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Protecting the Nation's Groundwater From Contamination

Volume II

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Foreword

At the request of the Senate Committee on Environment and Public Works, the Office of Technology Assessment has examined the current status of the Nation's knowledge about and experience in dealing with groundwater contamination problems. This volume of *Protecting the Nation's Groundwater From Contamination* presents in detail the information and data on which the analyses and conclusions of volume I are based. It is organized into eight appendixes covering health impacts and sources of groundwater contamination; the State framework for protecting groundwater quality based on results from the OTA State survey; technical and nontechnical issues related to the application of corrective action alternatives; and definitions of hydrogeologic terms.

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NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The views expressed in this OTA report, however, are the sole responsibility of the Office of Technology Assessment.

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Groundwater Contamination and Its Impacts

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A.1 AN APPROACH TO ASSESSING THE HEALTH RISKS OF CHEMICALS IN GROUNDWATER

Because of uncertainties about the relationship between exposure (e.g., to chemicals) and impacts on human health, public health efforts are based on identifying *probabilities* of impacts. This process entails identifying when exposure is likely to pose either *significant* health risks or, alternatively, *negligible* health risks.

Predictive risk assessment is generally accepted by the scientific community as the only currently available method for evaluating the risks posed by exposure to chemical contaminants under varying conditions. This approach and its limitations are described in detail in the literature (e.g., NAS, 1983a; Environ Corp., 1983). Importantly, what are deemed to be "safe" or "acceptable" levels of risk for the protection of public health involves subjective judgments, often including consideration of the costs of achieving those levels.

Predictive risk assessment has historically been applied to contaminants found in environmental media other than groundwater. Its application to groundwater is believed appropriate because many of the scientific and technical issues that motivated the use of predictive risk assessment in the past are independent of the environmental medium in which the contaminants occur (Environ Corp., 1983). Some of these issues concern the risks associated with chemical exposures that do not produce immediately observable effects or for which the nature and duration of the exposure cannot be readily identified. At the same time, the occurrence of contaminants in groundwater raises questions that have not yet been fully examined in the context of predictive risk assessment and public health protection; these questions are related, for example, to multiple pathways of exposure.

Conducting a risk assessment for groundwater contaminants consists of four basic steps (NAS, 1983a):

1. hazard evaluation, i.e., identification of the contaminants and their toxicological characteristics;
2. dose-response assessment, i.e., specification of the "no observed effect level" (NOEL) for non-carcinogens and of the unit risk for carcinogens;
3. exposure assessment, i.e., identification of the pathways of exposure, dosage, concentration levels, and exposed population; and
4. risk characterization, i.e., translation of the above three steps into a determination of health risks.

Each of these steps is described and analyzed below in the context of groundwater. Ultimate determination of risks requires that *each* of the four steps be carried out

Hazard Evaluation

Hazard evaluation involves collecting and assessing information about the inherent toxic properties of contaminants. There are two principal sources of information about toxic properties: 1) epidemiological or clinical studies and 2) experimental data. Molecular structure is presently of only limited value in predicting the toxic properties of chemicals (Environ Corp., 1983).

The limitations of epidemiological investigations in providing information about the toxic properties of chemicals are well described elsewhere (Environ Corp., 1983). In the context of groundwater contamination, the limitations would include:

- *Difficulties in providing proper controls on studies so that strict cause-effect relationships can be established:* Because there is so little experience in conducting epidemiological studies in the context of groundwater, there are many unresolved methodological issues concerning controls including removing sources of bias (e.g., effects of diet, cigarette smoking, and occupation), accounting for exposure to mixtures of contaminants that are also site-specific and time-varying, identifying suitable control groups, and detecting small but potentially important risks when small numbers of people are involved.
- *Difficulties in obtaining accurate data on the nature, intensity, and duration of exposure, especially when multiple chemicals are present at low concentrations:* Many contaminants are present in groundwater at low concentrations (e.g., parts per billion), and exposure may occur over long periods.
- *Difficulties in linking adverse health impacts that are observable only after long latency periods to exposure:* There is a general lack of data concerning possible health impacts on humans exposed to groundwater contamination. One systematic health investigation that was specifically oriented to groundwater suggested a relationship between high levels of carbon tetrachloride and liver damage in Hardeman County, TN (Clarke, et al., 1982, cited in Harris, 1983); however, this study involved a relatively short latency period and was not a controlled epidemiological study. Epidemiological studies related to drinking water include a set of studies that are inconclusive about an association between cardiovascular disease and chlorinated drinking water (see NAS, 1980) and studies suggesting an association between chlorinated drinking water and certain cancers (Crump, et al., 1980, cited in Harris, 1983). A recent study linked rates of leukemia and birth defects with the presence of chloroform and TCE in two wells in Woburn, MA (*Science News*, 1984).
- *Difficulties in applying the epidemiological methodology to newly introduced chemicals:* Although relatively few chemicals are widely used commercially, approximately 1,000 new chemicals are introduced into commercial production each year.
- *Difficulties in interpreting self-reported symptoms:* Self-reporting of symptoms is one of the earliest clues to a possible relationship between exposure and health impacts and can provide the basis for the design of testable, controlled epidemiological investigations. Evidence for a relationship is strong if reported symptoms are highly specific and unusual and appear to occur in "clusters." Even so, such evidence does not constitute proof of a causal link between exposure and reported symptoms. At best, reported symptoms can be checked for consistency with known hazards and serve to strengthen or weaken inferences about suspected relationships. If reported symptoms are vague and/or common (e.g., headaches, nausea, and rashes), it is unlikely that epidemiological studies will be of value (Environ Corp., 1983).

Because of the types of problems associated with epidemiological investigations, "it is **likely that most epidemiological investigations of populations exposed to groundwater contaminants would lead to inconclusive results, and there appears to be little prospect for improving this situation;** these problems are inherent to methods of epidemiology" (Environ Corp., 1983). However, when populations have large exposures to high concentrations of organic chemicals, such as in Hardeman County, epidemiological investigations may be able to document adverse health impacts. In addition, when epidemiological data are supplemented with laboratory data, the likelihood of establishing cause-effect relationships can increase (Harris, 1984).

In addition to epidemiological studies, a second major source of information about toxicity is experimental data. Toxicity data derived from laboratory experiments on animals have several advantages over epidemiological and clinical investigations: exposures can be controlled, biological changes can be examined in detail, and causal relationships between exposure and toxicity can be established with high certainty.

The applicability of animal data to humans depends on the assumption that biological activity is similar among various mammalian species. There appears to be substantial evidence to support the inference of human health effects based on results from animal studies (Environ Corp., 1983); and consequently, animal data have historically been the principal sources of toxicity data for assessing the risks of chemicals (e.g., pesticides, food and color additives, and drugs) prior to their commercial introduction. Nevertheless, inferences about human health effects from animal data are still controversial. In addition, although efforts are underway to develop toxicity data for various purposes (e.g., toxicity data are available from the National Toxicology Program of the Department of Health and Human Services), OTA's analysis suggests that **a com-**

plete, uniform data base for all potential groundwater contaminants is unlikely for many years (Environ Corp., 1983).

Dose-Response Relationships

The second step in a predictive risk assessment is describing dose-response relationships. These relationships link known exposure characteristics with the frequency at which toxic effects appear in exposed populations. In general, for a given duration of exposure, the frequency at which toxic effects appear in an exposed population increases with increasing dosage; in many cases, the toxic effects will become more severe as exposure increases (Environ Corp., 1983).

There are various ways to express dosage. The most common is weight of the contaminant taken into the body per unit of body weight of the exposed recipient per unit of time (e.g., milligrams (mg) per kilogram (kg) per day). Because epidemiological studies rarely provide the exposure data necessary for determining exposure characteristics, experimental data are the primary source of dose-response information.

In practice, inferences must often be made about the dose-response function for groundwater contaminants because doses are often below the range at which experimental dose-response relationships can be observed. Some cases of contamination, however, do involve exposures in the range for which experimental dose-response relationships have been determined (Harris, 1984). When the relationships can be determined, the dose-response for non-carcinogens is described in terms of the threshold dose at which no adverse response is observed, the "no observed effect level" (NOEL). For carcinogens, which do not appear to act according to a threshold concept, experimental data are used to establish a relationship between dose and carcinogenic risk known as the "unit risk," e.g., the fraction of a group of experimental animals exposed to carcinogens that develop tumors during the experiment minus the fraction of animals in the untreated (control) group that develop the same types of tumors. In general, experimentally derived measures of dose-response should be interpreted with care in estimating human dose-response relationships[1] (Environ Corp., 1983).

Exposure Assessment

Exposure assessment involves determining the magnitude and duration of exposure to environmental agents. It requires estimating the dosage of contaminants received by exposed populations, identifying the exposed population, and identifying the body sites at which toxic effects are produced.

The dosage of contaminants received by exposed human populations can be estimated if information is available about both concentration levels and the intake (e.g., duration, frequency, and amount) of contaminants at given concentration levels. Determining the intake of groundwater contaminants, however, is difficult because of the multiplicity of pathways along which the contaminants can expose populations (see ch. 2).

In practice, information is most often *not* available about the dosage received along these different pathways, and health scientists often assume standard average values when carrying out exposure assessments. Only for the direct ingestion of contaminants via drinking water are there standard approaches for estimating dosage. Although there appears to have been little attempt thus far to conduct comprehensive exposure analysis (Environ Corp., 1983), approaches for incorporating the different possible pathways of exposure have been discussed within the scientific community.[2]

Table A.1.1 lists the types of data and assumptions that would be necessary to estimate dosage from each possible route of exposure to groundwater contaminants. Because many of the parameters shown in table A.1.1 vary from site to site and thus cannot be readily standardized, exposure assessments will probably have to be made at the site-specific level. Further, daily concentrations of organic chemicals in groundwater can fluctuate by more than an order of magnitude. Accurate average exposures can be calculated only if a monitoring program is designed to account for this fluctuation; most monitoring data currently available are not adequate for calculation of accurate average exposure (Harris, 1984). This difficulty argues for careful site analysis of contaminant concentrations, soils, and the habits of the exposed populations.

Identification of exposed populations is important because different people exhibit different susceptibilities to a toxic agent. In most cases, the general population would be exposed and would exhibit the full range of susceptibilities. At some sites, however, principally

---

[1] For example, human thresholds are probably lower than experimentally derived NOELs both because the human population is genetically more diverse and thus likely to have a broader range of susceptibilities than laboratory animals, and because the human population is exposed to a broad range of additional environmental agents. Further, because only relatively small numbers of animals can be used in carcinogenicity experiments, the experiments often involve high doses of agents; extrapolating the results to human exposures from environmental carcinogens thus involves prediction of low dose risk from high dose/high risk data.

[2] For example, in the risk assessments conducted by the Safe Drinking Water Committee of the National Research Council (NRC), safe drinking water exposure limits were estimated on the basis of an arbitrary assumption that only 20 percent of a person's daily exposure to a contaminant would come from the direct ingestion of water. (See also NAS, 1983a; NRC, 1980.)

Table A-1.1.—Data and Assumptions Necessary To Estimate Human Dose of a Groundwater Contaminant From Knowledge of its Concentration in Groundwater[a]

1. Direct ingestion through drinking:
   - Amount of water consumed each day (generally assumed to be 2 liters for adults and 1 liter for a 10 kg child).
   - Fraction of contaminant absorbed through wall of gastrointestinal tract.
   - Contaminant concentrations.
   - Average human body weight.
2. Inhalation of contaminants:
   - Air concentrations resulting from showering, bathing, and other uses of water.
   - Variation in air concentrations over time.
   - Amount of contaminated air breathed during those activities that may lead to volatilization.
   - Fraction of inhaled contaminant absorbed through lungs.
   - Average human body weight.
3. Skin absorption from water:
   - Period of time spent washing and bathing.
   - Fraction of contaminant absorbed through skin during washing and bathing.
   - Average human body weight.
4. Skin absorption from contaminated soil:
   - Concentrations of contaminant in soil that has been exposed to contaminated groundwater.
   - Amount of daily skin contact with soil.
   - Amount of soil ingested per day (e.g., by children).
   - Absorption rates (e.g., by skin and gastrointestinal tract).
   - Average human body weight.
5. Ingestion of contaminated food:
   - Concentrations of contaminant in edible portions of various plants and animals that have been exposed to contaminated groundwater.
   - Amount of contaminated food ingested each day.
   - Fraction of contaminant absorbed through wall of gastrointestinal tract.
   - Average human body weight.

[a] The total dose is equal to the sum of the doses from the five routes.

SOURCE: Environ Corp., 1983.

subgroups will be exposed (e.g., children and the elderly), and they may exhibit specific susceptibilities.

Another aspect of exposure assessment involves identifying the body site at which toxic effects are produced. For example, some contaminants produce their toxic effects directly at the point of contact (e.g., the skin, lung, and gastrointestinal tract). If contaminants are to produce effects at internal body sites (systemic effects), they must first pass through physical barriers—i.e., the gastrointestinal wall, the skin, or the lungs. The rate and amount of absorption vary from contaminant to contaminant; these data are most frequently not available. In the absence of data from human subjects, the common practice among public health scientists is either to adopt absorption rate values from experimental studies of substances having similar chemical and physical characteristics or to assume that absorption is complete along every pathway (Environ Corp., 1983).

Risk Characterization

The fourth and last step in the risk assessment process is risk characterization. Once information is obtained about contaminant toxicity, dose-response relationships, and exposure, the risk faced by exposed populations can be determined.

With respect to non-carcinogens, common practice is to:

1. calculate an acceptable daily intake (ADI) level by dividing the experimentally determined NOEL by a safety factor (to account for uncertainties in the measurements);
2. modify the ADI if exposure routes other than ingestion are to be considered; otherwise incorporate additional safety factors; and
3. calculate the margin-of-safety (MOS) by dividing the experimental NOEL by the actual dose and compare the MOS to the safety factors used in calculating the ADI. (Note that the lower the value of the MOS, the larger the risk to the exposed population.)

For carcinogens, risk is characterized by multiplying the actual daily lifetime dose by the unit risk. Although an explicit estimate of risk is obtained, this estimate still embodies uncertainty and is treated (e.g., by FDA and EPA) as an upper limit of the true risk.

The ADI and the MOS for non-carcinogens and the acceptable risk for carcinogens are designed to ensure that exposed populations are not at significant risk. Although the calculation of these values for any given contaminant involves many simplifying assumptions and approximations, an additional limitation is that these estimates treat contaminants individually and independently of each other. In most instances, however, populations are exposed not to individual contaminants but to complex and possibly time-varying mixtures.

How and where contaminants interact with each other to produce toxic effects are complicated and poorly understood; some evidence suggests that such interactions are significant.[3] The health risks from exposure to combinations of contaminants may differ either qualitatively or quantitatively from health risks from exposure to individual contaminants. Although such interactions are not unique to groundwater, they do pose a significant impediment to reaching conclusions about acceptable levels of exposure to groundwater contaminants (Environ Corp., 1983).

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[3] Examples include the marked synergism between cigarette smoking and asbestos in the induction of lung cancer, the reaction of secondary amines and nitrites in the stomach to form carcinogenic nitrosamines, and the synergistic effects between alcohol and halogenated hydrocarbons (e.g., carbon tetrachloride) to cause liver damage (see Environ Corp., 1983, for complete references).

There are no generally applicable protocols for testing the effects of contaminant interactions, and there are few data to guide the development of such protocols. For now, risk assessments that are to take into account possible interactions must be based on considerations other than empirical evidence. Although the potential importance of interactions is recognized, especially with respect to groundwater, there is no area of standard setting that has taken interactions into account as a matter of course.[4]

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[4] EPA has considered treating carcinogenic risk as additive, i.e., that the total carcinogenic risk is equal to the sum of the risk of each of the individual contaminants (Environ Corp., 1983).

A.2 SUMMARY OF TOXIC EFFECTS OF ORGANIC AND INORGANIC CHEMICALS KNOWN TO OCCUR IN GROUNDWATER[a b]

CONTAMINANT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A.1. AROMATIC HYDROCARBONS																								
1. Acetanilide																								
2. Alkyl benzene sulfonates	X	X	X											X										
3. Aniline									X							X								X
4. Anthracene			X																				X	X
*5. Benzene	X	X	X						X	X	X	X		X										X
6. Benzidine																								X
7. Benzyl alcohol		X																						
8. Butoxymethylbenzene																								
9. Chrysene																								X
10. Creosote Mixture																								
11. Dibenz (a.h.) anthracene																								X
12. Di-t-butyl-p-benzoquinone																								
13. Dihydrotrimethylquinoline																								
14. 4,4-Dinitrosodiphenylamine																								X
*15. Ethylbenzene	X	X		X		X	X	X																
16. Fluoranthene																								
17. Fluorene																								
18. Fluorescein dye																								
19. Isopropyl benzene																								

CONTAMINANT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A.1. AROMATIC HYDROCARBONS (Continued)																								
20. Methylthiobenzothiazole																								
21. 4,4-Methylene-bis-2-chloroaniline (MOCA)	X			X		X	X									X							X	X
22. Naphthalene	X	X		X							X							X						
23. o-Nitroaniline																X							X	
24. Nitrobenzene						X	X		X		X					X			X	X	X			
25. 4-Nitrophenol					X											X								
26. n-Nitrosodiphenylamine						X																		X
27. Phenanthrene			X																				X	X
28. n-Propylbenzene										X														
29. Pyrene		X			X	X					X			X								X	X	
30. Styrene (vinyl benzene)	X	X		X		X	X		X					X							X		X	
*31. Toluene	X	X		X		X	X		X				X											
32. 1,2,4-Trimethylbenzene		X			X				X															
33. Xylenes (m,o,p)	X			X		X	X		X				X											

CONTAMINANT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A.2. OXYGENATED HYDROCARBONS																								
1. Acetic acid	X	X		X	X																			
2. Acetone	X			X					X															
3. Benzophenone			X																					
4. Butyl acetate																								
5. N-butyl-benzylphthalate																								
6. Di-n-butyl phthalate	X			X					X															
7. Diethyl ether	X	X		X					X															
8. Diethyl phthalate		X		X																				
9. Diisopropyl ether																								
10. 2,4- Dimethyl-3-hexanol																								
11. 2,4-Dimethyl phenol																								
12. Di-n-octyl phthalate																								
*13. 1,4-Dioxane	X			X		X	X																	X
14. Ethyl acrylate																								
15. Formic acid	X	X		X					X															
16. Methanol	X					X			X									X						
17. Methyl alcohol																								
18. Methylcyclohexanone																								
19. Methyl ethyl ketone																								
20. Methylphenyl acetamide																								

CONTAMINANT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A.2. OXYGENATED HYDROCARBONS (Continued)																								
*21. Phenols (e.g., p-tert-Butyl phenol)		X																						
22. Phthalic acid																								
23. 2-Propanol																								
24. 2-Propyl-1-heptanol																								
25. Tetrahydrofuran		X		X		X	X		X															
26. Varsol																								
A.3. HYDROCARBONS WITH SPECIFIC ELEMENTS																								
1. Acetyl chloride																								
*2. Alachlor (Lasso)																								
*3. Aldicarb (sulfoxide and sulfone; Temik)															X									
4. Aldrin		X				X	X		X											X				X
5. Atrazine		X			X				X		X										X		X	
6. Benzoyl chloride		X		X																				
7. Bromobenzene	X	X			X	X		X															X	
*8. Bromacil						X			X															
9. Bromochloromethane					X	X	X		X															
*10. Bromodichloromethane																								
11. Bromoform	X			X		X			X															
*12. Carbofuran						X									X									

CONTAMINANT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A.3. HYDROCARBONS WITH SPECIFIC ELEMENTS (Continued)																								
*13. Carbon tetrachloride						X	X		X											X				X
14. Chlordane				X		X			X				X											X
15. Chlorobenzene	X			X	X	X	X		X											X			X	
*16. Chloroform	X	X				X	X		X					X							X			X
17. Chlorohexane																								
18. Chloromethane					X	X	X		X															
19. Chloromethyl sulfide																								
20. 2-Chloronaphthalene		X				X																		
21. Chlorpyrifos						X									X									
22. Chlorthal-methyl (DCPA, or Dacthal)																								
23. o-Chlorotoluene	X	X							X															
24. p-Chlorotoluene																								
25. Dibromochloromethane																							X	
*26. Dibromochloropropane (DBCP)	X	X			X	X	X													X			X	X
27. Dibromodichloroethylene																								
28. Dibromoethane																								
29. Dibromomethane																								
30. Dichlofenthion (DCFT)															X									

CONTAMINANT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A.3. HYDROCARBONS WITH SPECIFIC ELEMENTS (Continued)																								
31. o-Dichlorobenzene	X	X		X	X	X	X		X		X													
*32. p-Dichlorobenzene	X			X	X	X	X		X		X													
33. Dichlorobenzidine	X			X	X									X										X
34. Dichlorocyclooctadiene																								
35. Dichlorodiphenyldichloroethane (DDD,TDE)																			X					X
36. Dichlorodiphenyldichloroethylene (DDE)																								
*37. Dichlorodiphenyltrichloroethane (DDT)					X	X			X		X									X			X	X
38. 1,1-Dichloroethane						X	X		X												X			
*39. 1,2-Dichloroethane	X	X			X	X	X		X				X	X					X	X			X	X
*40. 1,1-Dichloroethylene (vinylidiene chloride)	X	X		X	X	X	X		X				X						X		X		X	X
*41. 1,2-Dichloroethylene (cis and trans)																								
42. Dichloroethyl ether																								
43. Dichloroiodomethane																								
44. Dichloroisopropylether (= bis-2-chloroisopropylether)																								
*45. Dichloromethane (methylene chloride)	X	X				X	X		X												X			
46. Dichloropentadiene																								

CONTAMINANT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A.3. HYDROCARBONS WITH SPECIFIC ELEMENTS (Continued)																								
47. 2,4-Dichlorophenol																								
*48. 2,4-Dichlorophenoxyacetic acid (2,4-D)									X	X												X	X	
49. 1,2-Dichloropropane						X	X																X	
50. Dieldrin						X			X											X				X
51. Diiodomethane																								
52. Diisopropylmethyl phosphonate (DIMP)																								
53. Dimethyl disulfide																						X		
54. Dimethylformamide																								
55. 2,4-Dinotrophenol (Dinoseb, DNBP)	X	X					X		X											X				
*56. Dioxins (e.g., TCDD)						X			X	X							X			X		X	X	X
57. Dodecyl mercaptan (lauryl mercaptan)	X	X	X						X														X	
*58. Endosulfan						X	X		X												X		X	
59. Endrin						X			X															
60. Ethyl chloride																								
61. Bis-2-ethylhexylphthalate	X	X				X														X	X	X		X
62. Di-2-ethylhexylphthalate																								

CONTAMINANT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A.3. HYDROCARBONS WITH SPECIFIC ELEMENTS (Continued)																								
63. Fluorobenzene																								
64. Fluoroform																							X	
65. Heptachlor																								
66. Heptachlorepoxide																								
67. Hexachlorobicycloheptadiene																								
68. Hexachlorobutadiene																								
69. α - Hexachlorocyclohexane (=Benzenehexachloride, or α - BHC)																								
70. β - Hexachlorocyclohexane (β - BHC)																								
71. γ - Hexachlorocyclohexane (γ -BHC, Lindane)																								
72. Hexachlorocyclopentadiene	X			X	X	X	X						X						X					
73. Hexachloroethane						X	X		X												X			X
74. Hexachloronorbornadiene																								
75. Kepone						X	X													X	X			X
76. Malathion																								

CONTAMINANT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A.3. HYDROCARBONS WITH SPECIFIC ELEMENTS (Continued)																								
77. Methoxychlor							X													X				
78. Methyl bromide																								
*79. Methyl parathion																								
80. Parathion															X					X	X			
81. Pentachlorophenol (PCP)	X	X		X		X			X												X			
82. Phorate (Disulfoton)															X									
83. Polybrominated biphenyls (PBBs)						X						X									X	X		
*84. Polychlorinated biphenyls (PCBs)					X	X						X	X	X						X	X	X	X	X
85. Prometon																								
*86. RDX (Cyclonite)																							X	
87. Simazine									X															
*88. Tetrachlorobenzene																								
*89. Tetrachloroethane (1,1,1,2)						X															X		X	
*90. Tetrachloroethane (1,1,2,2,)				X		X	X		X					X							X	X	X	X
*91. Tetrachloroethylene (1,1,2,2) (perchloroethylene, PCE)	X			X	X		X		X												X			X
*92. Toxaphene						X	X		X												X		X	X
93. Triazine																								
94. 1,2,4-Trichlorobenzene																								

CONTAMINANT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A.3. HYDROCARBONS WITH SPECIFIC ELEMENTS (Continued)																								
*95. Trichloroethanes (1,1,1 & 1,1,2)	X	X		X	X	X	X		X				X										X	X
96. 1,1,2-Trichloroethyelene (TCE)		X			X	X	X		X		X		X											X
97. Trichlorofluoromethane (Freon 11)									X				X											
98. 2,4,6-Trichlorophenol						X																	X	X
99. 2,4,5-Trichlorophenoxyacetic acid (2,4,5-T)						X	X		X													X	X	
100. 2,4,5-Trichlorophenoxypropionic acid (2,4,5-TP, or Silvex)						X	X		X															
101. Trichlorotrifluoroethane																								
*102. Trinitrotoluene (TNT)																								
103. Tris-(2,3-dibromopropyl) phosphate																								
*104. Vinyl chloride		X				X	X		X		X												X	X
A.4. OTHER HYDROCARBONS																								
1. Alkyl sulfonates	X	X	X																					
2. Cyclohexane						X	X		X															
3. 1,3,5,7-Cyclooctatetraene																								
4. Dicyclopentadiene (DCPD)	X	X		X	X		X		X															
5. 2,3-Dimethylhexane																								
6. Fuel oil		X			X		X		X					X										

CONTAMINANT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A.4. OTHER HYDROCARBONS (Continued)																								
*7. Gasoline		X		X					X					X										
8. Jet fuels						X	X		X	X														
9. Kerosene																								
10. Lignin																								
11. Methylene Blue Activated Substances (MBAs)																								
12. Propane													X											
13. Tannin																								
14. 4,6,8-Trimethyl-1-nonene																								
15. Undecane																								
B.1. METALS AND CATIONS																								
*1. Aluminum														X										
2. Antimony		X			X	X	X				X		X											
*3. Arsenic					X					X			X				X			X		X	X	X
*4. Barium		X		X	X		X			X									X					
*5. Beryllium	X	X	X	X	X	X																		X
*6. Cadmium				X	X		X		X											X	X	X		X
7. Calcium																								
*8. Chromium		X	X	X	X	X															X	X	X	X
*9. Cobalt	X	X	X		X						X		X	X										

CONTAMINANT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
B.1. METALS AND CATIONS (Continued)																								
10. Copper						X	X					X												
*11. Iron					X	X								X										
*12. Lead									X		X									X				
13. Lithium							X		X				X	X										
14. Magnesium	X								X															
*15. Manganese					X	X			X															
*16. Mercury							X		X									X				X		
*17. Molybdenum																								
*18. Nickel	X		X	X	X				X					X						X				X
19. Palladium							X				X													
20. Potassium																								
*21. Selenium	X			X	X	X			X					X										
*22. Silver					X		X				X			X			X	X						
*23. Sodium																								
24. Thallium						X	X		X				X	X						X		X		
25. Titanium																								
*26. Vanadium			X		X	X	X		X		X													
*27. Zinc	X	X									X								X	X				

CONTAMINANT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
B.2. NONMETALS AND ANIONS																								
*1. Ammonia	X	X		X	X	X	X		X															
2. Boron																								
*3. Chlorides																								
*4. Cyanides	X	X	X	X					X															
*5. Fluorides							X		X															
*6. Nitrates																								
7. Nitrites																								
8. Phosphates																								
*9. Sulfates																								
10. Sulfites																								
TOTAL NUMBER OF CHEMICALS	43	46	13	38	37	62	53	2	67	6	17	4	16	18	6	5	3	4	7	21	20	14	31	38

Footnotes

[a] Compiled from a partial survey of literature conducted by Environ Corp., 1983.

"*" indicates that the chemical is known to exceed at least one State or Federal standard (see chapter 2, the section on Adverse Impacts of Chemicals, and app. A.4).

[b] Numerical key of toxic effects:

1. Eye irritation
2. Skin irritation
3. Allergic sensitization
4. Upper respiratory tract irritation
5. Lung/respiratory effects
6. Liver damage
7. Kidney damage
8. Pancreatic damage
9. Central nervous system (CNS) effects
10. Peripheral nervous system effects
11. Blood cell disorders
12. Immunological effects
13. Cardiovascular effects
14. Gastrointestinal effects
15. Cholinesterase inhibition
16. Methemoglobinemia
17. Skin damage
18. Visual damage
19. Endocrine effects
20. Reproductive effects
21. Embryotoxicity
22. Teratogenicity
23. Mutagenicity
24. Carcinogenicity

Source: Office of Technology Assessment.

A.3 FREQUENCY OF DETECTION OF SELECTED CHEMICALS IN GROUNDWATER

CHEMICAL	SAMPLING SCHEME Random	 Non-random	 Not specified
A.1. AROMATIC HYDROCARBONS			
Benzene		1.7-15	8.5
Ethylbenzene		0.6-44	
Fluoranthene			6.9
Propylbenzene		0.2	
Toluene		1.0-5.2	<5.0
Xylenes		1.7-2.1	<5.0
A.2. OXYGENATED HYDROCARBONS			
Acetone		2.6	
Butyl acetate			< 5.0
Di-n-butyl phthalate			28.6
Dichlorophenol			17.2
Diethyl phthalate			14.3
Methyl ethyl ketone			< 5.0
Phthalic acid			21.4
A.3. HYDROCARBONS WITH SPECIFIC ELEMENTS			
Bromobenzene		0.4	
Bromodichloromethane		50.9	69.2
Bromoform		30.9	36.3
Carbon tetrachloride		3.1-7.4	5-50
Chlorobenzene		0.2	7.1
Chloroform		11-53.2	70.3
Chloromethane (Methyl chloride)		3.7	

CHEMICAL	SAMPLING SCHEME Random	 Non-random	 Not specified
Chlorotoluene		0.2	
Dibromochloromethane		46.3	64.5
Dibromochloropropane (DBCP)		2.6	
Dichlorobenzene		0.8	12.9
Dichloroiodomethane		2.7	30.3
1,1-Dichloroethane		1.9-23.1	1-34
1,2-Dichloroethane	1.1-7.0	1.5-17.1	2-73
1,1-Dichloroethylene		3.1	7.1
1,2-Dichloroethylene		4.8-38.5	7.1-21.4
Dichloromethane			6.7
2,4-Dichlorophenol			17.2
1,2-Dichloropropane		1.5	
Ethyl chloride			7.1
Malathion			7.1
Methyl parathion			7.1
Pentachlorophenol (PCP)			6.9
Polychlorinated biphenyls (PCB)		7.8	
Tetrachloroethylene		2.1-9.4	2-34
Trichloroethanes (TCA)	4.3-8.1	8.1-15.8	2-66
Trichloroethylene (TCE)	1.7-11.3	3.6-50.1	2-79
Vinyl chloride		1.3	1-36

Source: Office of Technology Assessment; University of Oklahoma, 1983.

A.4 SUBSTANCES IN GROUNDWATER WHOSE DETECTED CONCENTRATION HAS EXCEEDED STANDARDS AND TYPES OF STANDARDS EXCEEDED

	State	State	National DW		Health Advisory			Ambient Water Quality
SUBSTANCE	DW	GW	Primary	Secondary	1-Day	10-day	Long-term	Control
A.1. AROMATIC HYDROCARBONS								
Benzene	X	X				X	X	X
Ethyl benzene								X
Toluene	X	X				X	X	
A.2. OXYGENATED HYDROCARBONS								
1,4-Dioxane	X	X				X		
Phenols	X	X						X
A.3. HYDROCARBONS WITH SPECIFIC ELEMENTS								
Alachlor		X						
Aldicarb	X	X						
Bromacil		X						
Bromodichloromethane								X
Carbofuran	X				X	X	X	
Carbon tetrachloride	X	X			X	X		X
Chloroform		X						X
Dibromochloropropane (DBCP)	X	X						
Dibromoethane	X							
Dichlorobenzene (-p)								
Dichlorodiphenyltrichloroethane (DDT)		X						X
1,2-Dichloroethane	X	X						X
1,1-Dichloroethylene	X	X			X	X	X	X
1,2-Dichloroethylene	X	X			X	X		
Dichloromethane (methylene chloride)	X	X				X	X	X
2,4-Dichlorophenoxyacetic acid (2,4-D)	X	X	X					
Dichloropropane	X							
Dioxins		X						
Endosulfan		X						
β-Hexachlorocyclohexane	X							
α-Hexachlorocyclohexane	X							
γ-Hexachlorocyclohexane (γ-BHC, or Lindane)		X	X					
Methyl parathion		X						

			National DW		Health Advisory			Ambient Water Quality
SUBSTANCE	State DW	State GW	Primary	Secondary	1-Day	10-day	Long-term	Control
A.3. HYDROCARBONS WITH SPECIFIC ELEMENTS (cont'd)								
Polychlorinated biphenyls (PCBs)	X	X				X		X
RDX (Cyclonite)								X
Tetrachlorobenzene								X
Tetrachloroethane								X
Tetrachloroethylene	X	X			X	X	X	X
Toxaphene		X	X					X
1,1,1-Trichloroethane	X	X					X	X
Trichloroethylene (TCE)	X	X			X	X	X	X
Trinitrotoluene (TNT)								X
Vinyl chloride	X	X						X
A.4. OTHER HYDROCARBONS								
Gasoline	X	X						
B.1. METALS AND CATIONS								
Aluminum		X						
Arsenic	X	X	X					X
Barium		X	X					
Beryllium								X
Cadmium		X	X					X
Chromium		X	X					X
Cobalt		X						
Copper		X						X
Iron	X	X		X				
Lead		X	X					X
Manganese	X	X		X				
Mercury		X	X					X
Molybdenum		X						
Nickel		X						X
Selenium		X	X				X	
Silver		X	X					X
Sodium	X	X						
Vanadium		X						
Zinc		X		X				X
B.2. NONMETALS AND ANIONS								
Ammonia		X						
Chlorides		X		X				

SUBSTANCE	State DW	State GW	National DW		Health Advisory			Ambient Water Quality Control
			Primary	Secondary	1-Day	10-day	Long-term	
B.2. NONMETALS AND ANIONS (cont'd)								
Cyanides	X	X						X
Fluorides	X	X	X					
Nitrates		X	X					
Sulfates		X		X				
D. RADIONUCLIDES								
Radium 226	X	X	X					
Uranium 238		X					X	

Abbreviations: DW = drinking water; GW = groundwater.

"X" in State DW or State GW column means that the standard set by at least one State has been exceeded.

Source: Office of Technology Assessment.

A.5 SOURCES OF GROUNDWATER CONTAMINATION

This appendix was compiled to supplement and/or substantiate information summarized in chapter 2 (see table 8). Although an extensive survey of sources was attempted, time limitations precluded collecting some data. Thus the information in this appendix is that which was readily available to OTA; it should not necessarily be regarded as exhaustive or definitive.

When available and appropriate, this appendix contains the following information for each source:

- general information regarding the definition, use, and location of the source;
- details of the assumptions and calculations used in estimating the numbers of facilities or activities of a source type;
- details of the assumptions and calculations used in estimating the amount of material flowing through or stored in all facilities or activities of a source type; and
- information regarding the potential of both *individual* facilities or activities and *all* facilities or activities of a source type to contaminate groundwater.

Selected references on the potential of sources to contaminate groundwater are listed at the end of the appendix.

1. Subsurface Percolation: Septic Tanks and Cesspools

Septic tank systems consist of a buried tank and drainage system designed to collect waterborne wastes, remove settleable solids from the liquid by gravity separation, and permit percolation into the soil of clarified effluent. They are best suited for small volumes and periodic flows.

The highest regional densities of use in the United States occur in the eastern third of the country and along portions of the west coast (USDA, 1981a). Septic tank systems and cesspools serve more than 100,000 housing units in four counties (Nassau and Suffolk, NY; Dade, FL; and Los Angeles, CA) and more than 50,000 housing units in 23 counties (EPA, 1977a).

Development of Estimates of Numbers and Amounts

There were an estimated 19.5 million *domestic* onsite disposal systems in the United States in the mid-1970s, of which 16.6 million were septic tanks and cesspools (EPA, 1977a); presumably the remaining 2.9 million systems were privies or chemical toilets. Little information is available regarding the number of *commercial and industrial* septic tank systems. DeWalle, et al. (1980, cited in DeWalle, et al., no date) estimated that the State of Washington has at least 500 large onsite systems serving restaurants, hospitals, and larger industrial customers. Miller (1980) estimated that 25,000 industrial septic tanks are in operation in the United States based on the number of industrial establishments using water, but no documentation for the figure was provided.

Estimates of annual flow to an individual septic tank from an average household range from 49,275 gallons per year per household (gyh) (Miller, 1980: 45 gallons per person per day × 3 persons per household × 365 days per year) to approximately 75,000 gyh (derived from information in Pye, et al., 1983: 3.5 billion gallons per day × 365 days per year ÷ 17 million tanks). Thus a minimum estimate of the total annual flow to all domestic systems would be approximately 820 billion gallons per year (49,275 gyh × 16.6 million systems), and a maximum estimate would be approximately 1,460 billion gallons per year (75,000 gyh × 19.5 million systems).

Little direct information is available about flow rates to and leakage from industrial septic tanks. Assuming that the use of industrial septic tanks is comparable to domestic systems, there could be an estimated annual flow of approximately 1.2-1.9 billion gallons (minimum estimate: 49,275 gallons per year × 25,000 systems; maximum estimate: 75,000 gallons per year × 25,000 systems).

The range of estimates for domestic systems is probably very near to the actual amount because the underlying assumptions and data are based on studies of domestic systems (e.g., data are cited in: EPA, 1977a; Miller, 1980; Pye, et al., 1983). The estimates for industrial systems could be incorrect by more than 100 percent because information is lacking on annual flow to individual systems and no systematic surveys of numbers have been conducted on a nationwide basis.

Potential for Groundwater Contamination

Of all the sources known to contribute to groundwater contamination, septic tank systems and cesspools directly discharge the largest volume of wastewater into the subsurface. They are also the most frequently reported source of contamination (EPA, 1977a), and they contribute to both local and regional problems. Contaminants are principally from human wastes and household piping systems and include: nitrate, chloride, and coliform bacteria (e.g., DeWalle, et al., 1980); various metals (e.g., lead, zinc, copper, manganese, tin, and iron; Miller, 1980); viruses (Hain, et al., 1979); and others (e.g., see Miller, 1980).

The estimates of total annual discharge represent the potential volume of leachate released from the source. These figures are not equal to the volume of contaminated wastewater reaching groundwater because of renovative capacities of the soil system and evaporative losses from septic tank drain fluids (which occur even though the tanks are located in the soil) (Canter, et al., 1983).

Major factors affecting the potential of septic systems to contaminate groundwater in general are the density of systems per unit area and hydrogeological conditions. Areas with a density of more than 40 systems per square mile are considered regions with potential for contamination (EPA, 1977a); based on this criterion, portions of the Eastern United States and California exhibit the greatest potential for contamination. Local problems with septic tank systems can occur when individual systems are overloaded or when additives (e.g., TCE) are used to clean and unclog septic lines. Experiments conducted in Suffolk County, NY, confirm that organic cleaning solvents can leach from cesspools into groundwater (Andreoli, et al., 1980). Approximately 400,000 gallons of septic tank cleaning fluids (containing TCE, benzene, and dichloromethane (methylene chloride)) were used by homeowners in 1979 on Long Island alone (Burmaster, et al., 1982).

The design lives of septic tank systems are typically 20-40 years, after which time deterioration is likely. Design considerations for the percolation of effluent relate to the soil absorption system: the flow regime, the storage and carrying capacity of the receiving soil, the attenuation capacity of the biological mat in the leaching field, the subsurface soil type, and depth to the water table (Laak, et al., 1974).

2. Injection Wells

Several types of injection wells are used to inject or discharge wastes into or perform other functions in the subsurface:

- hazardous waste wells;
- non-hazardous waste wells (e.g., brine injection wells, and agricultural, urban runoff, and sewage disposal wells); and
- non-waste wells (e.g., wells for enhanced oil recovery, artificial recharge, in-situ recovery, and solution mining).

Hazardous waste wells are highly localized but can be expected to be regionally concentrated near industrial generators of these wastes.

Among the *non-hazardous waste wells,* agricultural wells are located in farming areas while urban runoff and sewage disposal wells are located primarily in urban areas. Because brine is a byproduct of oil production, brine injection wells are located primarily in areas of oil and gas production (e.g., the Southwest, Louisiana, Pennsylvania; University of Oklahoma, 1983).

Among the *non-waste wells,* enhanced oil recovery (EOR, also known as tertiary) wells follow a distribution pattern similar to that of oil production wells. Artificial recharge wells are usually located in areas of limited or vulnerable groundwater supplies; two major areas are in the High Plains (Ogallala Aquifer) and in coastal areas (e.g., to minimize salt-water intrusion). In-situ recovery wells are generally located in the oil shale regions of the Rocky Mountains. Solution mining injection wells are generally associated with uranium resources in the Southwest.

Development of Estimates of Numbers and Amounts

Hazardous Waste Wells.—Injection wells used primarily for hazardous waste disposal numbered approximately 280 in 1973 (Pye, et al., 1983). In 1981, 8.6 billion gallons of hazardous wastes were disposed of at 87 injection well sites (Dietz, et al., 1984).

The total number of injection wells is not known, and the validity of extrapolating data from strictly hazardous waste injection wells to all injection wells (even if most of them are used for hazardous waste disposal) is questionable. Other data indicate that as much as 11 percent of the Nation's liquid wastes may be disposed of in underground injection wells (Feliciano, 1983).

Brine Injection Wells and Enhanced Oil Recovery Wells.—Brine injection wells and enhanced oil recovery (EOR) wells are treated together here (and separately from non-hazardous waste wells and non-waste wells, respectively) for two reasons. First, more information is available for these wells than for other non-hazardous waste and non-waste wells. Second, EOR wells are injection wells used in tertiary oil production, and brine often is the injection fluid used in the EOR process.

In the early part of the century, most brine was disposed of in simple pits and caused many groundwater problems. Most States now ban the disposal of brine in pits, so most brine is disposed of in injection wells; illegal brine dumping into pits and streams and onto roads is a problem in some areas (e.g., Ohio; Dalton, 1983).[1] In recent years, at least 17 States have reported brine-related contamination incidents (Miller, 1980). For example, in Texas in the 1960s, approximately 69 percent of brine was reinjected, 21 percent was disposed of in pits, and 10 percent was discharged onto surface water; and approximately 23,000 contamination incidents were reported (University of Oklahoma, 1983).

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[1] Illegal brine dumping may be prevalent in some areas of the country. For example, Dalton (1983) states that excessive brine is often dumped on roads for dust control, beyond legal limits, and that some companies have been observed dumping brine directly into streams. However, the Ohio Oil & Gas Association (cited by Abbott, 1983) contends that some brine is legally used on roads for dust control and disputes the allegations of illegal dumping.

Miller (1980) estimated that 60,000 brine injection wells were in operation in the 1970s. A recent report indicated that 140,000 injection wells are used either for disposal of brine fluids brought to the surface during oil and gas production or for the injection of fluids in EOR processes (Kaplan, et al., 1983). EPA (1983a) listed over 119,000 EOR wells and an additional 37,000 injection and disposal wells (not all of which were used for brine disposal or EOR processes) in its Federal Underground Injection Control Reporting System (EPA, 1983a). Given these figures, it seems reasonable to conclude at this time that the number of brine disposal and EOR wells totals approximately 140,000.

Miller (1980) also estimated that approximately 460 billion gallons of brine per year were disposed of in injection wells. (Note that Miller indicated 260 bgy on p. 511 but 460 bgy p. 304; 460 bgy was the figure given by Fairchild, et al., 1980, cited in University of Oklahoma, 1983). The OTA updated estimate of the amount of brine disposal is based on estimates of brine production: although varying widely in different areas and operations, approximately 4 barrels (bbls) of brine are produced for every barrel of oil produced (Kaplan, et al., 1983), and approximately 8.55 million bbls of crude oil were produced per day in 1981 (CEQ, 1982). Given these figures, approximately 525 billion gallons of brine would be produced annually (8.55 million bbls oil per day × 4 bbls brine/bbl crude oil × 365 days per year × 42 gallons/bbl), and most of the brine is injected into wells.

The current level of oil produced from EOR processes is approximately 400,000 bbls/day (Kaplan, et al., 1983). The number of barrels of water injected per barrel of oil produced varies greatly depending on the particular EOR production process (Royce, et al., 1982). Assuming that 4 bbls of water are injected per barrel of oil produced (this figure is well within the range of figures presented in Royce, et al., 1982), then approximately 24.5 billion gallons of water per year would be injected in EOR processes (400,000 bbl per day × 4 bbl water per bbl oil × 365 days per year × 42 gallons/bbl).

Non-hazardous Waste Wells (excluding brine disposal wells).—Miller (1980) stated that at least 40,000 agricultural, urban runoff, and sewage disposal wells were in operation but that this estimate was probably much too low. For example, Miller cited 15,000 such wells in Florida; information obtained for OTA's study indicates there may be as many as 10,000 runoff wells in Phoenix, AZ (University of Oklahoma, 1983). Kaplan, et al. (1983) estimated that approximately 500,000 injection wells are in existence, of which approximately 140,000 are used in brine disposal or EOR processes; thus there would be approximately 360,000 other disposal wells in operation, presumably for agricultural, urban runoff, and sewage disposal purposes. It is not possible at this time to estimate the volumes of materials flowing through these wells. An on-going EPA inventory of Class V injection wells (e.g., surface water drainage, air-conditioning return, and other wells) will not be completed at least until 1985 (Anzzolin, 1983).

Non-waste Wells (excluding EOR wells).—At least 12,000 solution mining wells (including sulfur mining via the Freische method) are in operation (EPA, 1983a). No information was available regarding the amounts of materials involved in these operations.

Potential for Groundwater Contamination

EPA (1979) estimated that at least 21,000 injection wells in the United States require corrective action. Although injection wells can be constructed, operated, and monitored properly, contamination of groundwater can occur in a number of ways, primarily related to the construction, operation, and eventual closing of the wells (EPA, 1979):

1. faulty well construction (e.g., drilling and casing);
2. the forcing upward of pressurized fluids into nearby wells and groundwater formations (see below);
3. the forcing upward of pressurized fluids into faults or fractures in confining beds;
4. injection into or above usable aquifers (e.g., drinking water supplies);
5. the migration of fluids into hydrologically connected usable aquifers (e.g., drinking water supplies); and
6. faulty well closing.

The second item on the EPA list above may be of major significance in regions where heavy oil and gas production and associated brine wells are located because it includes abandoned and poorly maintained production wells. These wells are a potential source of contamination because brines injected into disposal wells can move laterally through the injection zone into unplugged, uncapped, or abandoned wells and subsequently leak into groundwater formations (Burmaster, et al., 1982; Kaplan, et al., 1983; Thornhill, 1975). Kaplan, et al. (1983) estimated that there are approximately 1.2 million abandoned wells (production wells, and mineral exploration and testing wells; see also Gass, et al., 1977) near areas of underground injection wells and, further, that the location of many abandoned wells is not known.

Depending primarily on the quality of recharge water, artificial recharge systems can alter groundwater quality; such alterations may also change the aquifer biologically

(University of Oklahoma, 1983). Soils can be clogged by suspended matter in the recharge water and by the associated biological activity. Even the disposal of a simple waste such as air conditioning return water can degrade groundwater by raising the temperature and adding chemicals (e.g., heavy metals).

3. Land Application

Land application of treated wastewater and wastewater byproducts (i.e., sewage sludge) is often used in place of more costly disposal processes. Its primary goals are the biodegradation, immobilization, and/or stabilization of various chemicals, and the beneficial use of nutrients contained in the wastewater or sludge. The wastewater itself is applied primarily by spray irrigation. Sludge is applied on agricultural or forest lands, used as commercial compost, disposed of in landfills, and applied in land reclamation projects (e.g., for strip mine reclamation; Weiss, 1983). Sludge is also disposed of by incineration and by ocean dumping (EPA, 1983b).

Most of the information available concerns municipal sludge characteristics and production. However, industrial sludge is sometimes disposed of in landfills. Industrial sludge includes effluent treatment sludge, stack scrubber residue, fly and bottom ash, slag, and numerous other manufacturing residues. In general, the production of sludge is concentrated around major industrial and population centers but land application is generally practiced in less populous areas (e.g., cropland) (University of Oklahoma, 1983).

Development of Estimates of Numbers and Amounts

The exact number and average size of sludge-spreading operations for municipalities is not known, but at least 2,463 publicly owned treatment facilities applying liquid or thickened sludge on land and 485 using spray irrigation were in operation or under construction in 1982 (EPA, 1983c).

About 6.8 million dry tons of sludge were produced by municipalities in 1982 (EPA, 1983b). Between 24 and 29 percent of the sludge generated in the United States is spread directly on crops (EPA, 1981b, 1983b). Another 18-21 percent is distributed free or is marketed, and most of it is subsequently deposited on cropland. Thus 40-50 percent of the municipal sludge generated—3-4 million dry tons per year—is used in some kind of direct land application.

Data are lacking on the amounts of industrial sludge produced annually and the number of sites involved but most of it is thought to be disposed of in solid waste sites and lagoons (Miller, 1980). During 1981, 70 hazardous waste land treatment facilities (excluding landfills) regulated by EPA under RCRA regulations treated approximately 0.1 billion gallons of hazardous wastes (Dietz, et al., 1984).

Potential for Groundwater Contamination

Groundwater contamination can occur when substances in sludge are leached by precipitation after the sludge is applied to the land. The substances of most concern include nitrogen, phosphorus, and heavy metals (EPA, 1983b); heavy metals also can limit the use of sludge in agriculture because they can be absorbed into the cover crop (Gurnham, et al., 1979).

The rate and duration of sludge application are determined by soil types, the nitrogen, phosphorus, and heavy metal content of the wastes, length of the irrigation season, and the nutrient uptake characteristics of the cover crop (Knox, et al., 1980; Young, 1978). Most States consider land application of municipal sludge at an agronomic rate (i.e., annual rate at which the nitrogen and/or phosphorus available to the crop from sludge does not exceed the annual nitrogen and/or phosphorus requirements of the crop) to have little potential for contamination of groundwater (EPA, 1983b). Reduction of application rates before planting and addition of nutrients near crop roots during the growing season ("side-dressing") also may alleviate some problems (Swanson, 1983). Heavy metals in municipal sewage are contributed by industry (e.g., electroplating and metal-finishing industries; other metal production, processing, and fabrication industries; and nominally non-metal industries), commercial establishments, domestic water supplies, and non-food household commodities (Gurnham, et al., 1979). The potential for contamination by heavy metals may be minimized if quality control procedures (e.g., industrial pretreatment and wastewater and sludge monitoring) are followed.

4. Landfills

The solid wastes deposited in landfills are generally classified as hazardous or non-hazardous. Hazardous solid wastes are specifically defined under RCRA regulations (see OTA, 1983a); various waste products are excluded from the definition: domestic sewage wastes, irrigation return flows, radioactive wastes, and some industrial wastes. Non-hazardous solid wastes as defined here encompass all solid wastes not included in the RCRA definition of hazardous wastes.

Solid waste products (e.g., from residences, small industries, and commercial activities) are generally deposited in municipal landfills; these wastes are usually, but not always, non-hazardous. Sanitary municipal landfills are landfills that are designed to minimize adverse environmental impacts (Miller, 1980). Industrial landfills are used for the disposal of solid wastes from large industries; the wastes are often hazardous.

The distribution of municipal landfills is assumed to follow the general distribution of population and thus should be concentrated around urban population centers. Most sanitary municipal landfills are small operations: about 80 percent of the sanitary landfills handle less than 50 tons of waste per day, and approximately 1 percent handle amounts in excess of 1,000 tons per day (*Waste Age*, 1981). Industrial landfills are probably concentrated near industrial facilities.

Development of Estimates of Numbers

The number of municipal solid waste land disposal sites is not easily determined. EPA's 1977 Report to Congress (1977a; see also Miller, 1980) estimated the number to be 18,500. This figure included not only sanitary municipal landfills but also some industrial landfills and open dumps; only about 5,600 were *licensed* sanitary landfills and most of the remaining sites were open dumps (Petersen, 1983). A recent survey estimated a total of 12,991 landfills in the United States (Petersen, 1983). These estimates included primarily sanitary municipal landfills but it also included non-hazardous industrial sites and 2,395 open dumps. Thus fewer than 10,000 sanitary municipal operations are known to be in operation (how many fewer than the 10,000 is not known because the number of industrial sites was not specified). In addition, the number of abandoned or closed municipal landfills and open dumps could be equal to the number of known sanitary municipal landfills (Eldridge, 1978). Thus a first approximation of the number of municipal landfills in the Nation might be 15,000-20,000 (fewer than 10,000 municipal landfills × 2, to account for both operating *and* abandoned or closed municipal landfills; see the discussion on *Open Dumps*, below). Conservatively, this estimate is probably correct within a range of 100 percent.

The exact number of industrial solid waste land disposal sites is not known, but EPA has estimated that there are 75,700 active landfill sites for industrial wastes (CEQ, 1981b). About 199 hazardous waste landfill facilities are known (Dietz, et al., 1984). In addition, a large portion of industrial solid wastes, including some that are considered hazardous, are disposed of in municipal landfills (Miller, 1980).

Development of Estimates of Amounts

Approximately 138 million tons of municipal solid wastes were handled by municipal solid waste disposal facilities during 1978 (CEQ, 1982). This figure is probably a relatively accurate estimate of the amount of solid wastes handled annually by sanitary landfill facilities because it is based on relatively extensive nationwide surveys.

Estimates of the amounts of non-hazardous industrial solid wastes and of hazardous wastes disposed of in landfills are not as accurate. The range of estimates for *non-hazardous industrial solid wastes* is 40-140 million wet tons per year. The minimum estimate of 40 million wet tons per year is derived as follows. Approximately 150 million tons of *total solid* wastes were generated by industry in 1980 (CEQ, 1982), and approximately 45 million wet tons were hazardous (EPA, 1981b); thus 105 million wet tons were non-hazardous industrial solid wastes (150 mty − 45 mty). Assuming that the proportion of solid wastes disposed of in landfills is the same for industry's non-hazardous solid wastes as it is for hazardous solid wastes (40 percent),[2] then the minimum amount disposed of is approximately 40 million wet tons per year (0.40 × 105 mty).

The maximum estimate of the amount of non-hazardous industrial solid waste disposal is approximately 140 million wet tons per year. This estimate is derived by applying the 40 percent rate to the higher EPA estimate of 342 million tons for non-hazardous industrial solid waste production in 1980 (EPA, 1981b) (40 percent × 342 mty = 140 mty).

At least 0.81 billion gallons of hazardous wastes were disposed of in 199 landfill facilities in 1981 (Dietz, et al., 1984); this figure includes both liquid and solid wastes.

Utilities generate approximately 77 million wet tons of solid waste per year (EPA, 1981b), most of which is fly and bottom ash from the burning of fossil fuels (approximately 73 million tons of ash are generated annually; OTA, 1983a). Assuming that 40 percent is disposed of in landfills, an estimated 30 million tons of solid wastes per year generated by utilities would be disposed of in landfills; the applicability of the 40 percent disposal rate assumption to utilities is not known.

Note that approximately 13-15 percent of municipal sludge produced is disposed of at landfills (EPA, 1981b; EPA, 1983b), but this amount results in landfill disposal of only about 1 million tons per year (15 percent of the estimated 6.8 million tons of municipal sludge; see *Land Application*, above). This amount is included within the rounding errors in the above estimates.

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[2] Approximately 40 percent of industry's hazardous *solid* wastes is disposed of in landfills of some type (EPA, 1981b). The remainder is disposed of by chemical, biological, or physical treatment; deep well injection; land treatment; resource recovery; or incineration.

Potential for Groundwater Contamination

Considerations in the design of municipal landfills include the location, the area to be served, and plans for different stages in the filling process (e.g., use upon completion of the fill). Provisions must be made for controlling traffic, unloading and handling different types of wastes, placement of cover materials, fire control, control of salvage and scavenging, and monitoring. Industrial landfills have similar design, operation, and maintenance needs, although the nature of the wastes disposed of may entail additional safety considerations (hazardous waste landfills are included in this category).

Groundwater contamination can be minimized by proper design, construction, and operation and maintenance of a facility (Brunner, et al., 1972). However, facilities are not always maintained properly and some landfills are allowed to deteriorate (University of Oklahoma, 1983). Further, not all contamination controls used in landfills are effective; for example, required liners—of both natural and synthetic materials—have cracked or deteriorated when exposed to certain chemicals (OTA, 1983a). Abandoned landfills (the locations of which are not usually known to regulatory authorities) often pose a threat to groundwater quality because geologic and hydrologic characteristics were not considered in the original site selection; the same may be true for some active landfills. Many abandoned landfills were located in sand and gravel quarry pits or in environmentally sensitive areas such as marsh lands. Only 1,609 of almost 13,000 landfills surveyed reported having monitoring systems for groundwater, leachate, and/or gas in 1983 (Petersen, 1983).

Leachate generation varies with time over a facility's life, so the age of facilities could affect the amount and strength of the leachate. In addition, the amount of leachate leaving the more recent facilities could be significantly less than at older facilities. Many older landfills were not lined; and leachate collection and treatment have become common practices at a number of the more recent facilities (in the last 10 years).

Unless moisture can be totally prevented from entering a landfill, leachate will eventually be generated. Once a landfill system reaches its disposal capacity, leachate generation is directly related to the volume of water added to the system (University of Oklahoma, 1983). Leachate generation also depends on the initial moisture content of the wastes, the landfill density, the rate of filling, and infiltration water quantities. Infiltration from the surface is not the only source of water coming into a landfill; although undesirable, some landfills intersect aquifers, thereby creating another source of moisture for leachate generation.

Techniques for estimating the amount of leachate generation from landfills vary widely in their results. Assumptions that affect the estimates include the choice of runoff coefficients, the moisture storage capacity of the waste, and evapotranspiration rates. Lu, et al. (1981) found that the error range of 25 different methods for predicting leachate generation was 1.3-5,400 percent (as reported in University of Oklahoma, 1983).

Even if the amount of leachate generated is known, not all of it reaches the groundwater. Depending on soil type and the position of the water table, the soil underlying the wastes will be able to attenuate or renovate some leachate before it reaches the groundwater. In order to develop accurate estimates of the potential for leachate to contribute to groundwater contamination, estimates must include a percentage reduction for absorption and attenuation.

5. Open Dumps

A dump is a land disposal site where solid wastes are deposited indiscriminately, with little or no regard for the design, operation, maintenance, or esthetics of the site. In an "open" dump, the wastes are almost always left uncovered. Most often the open dump is not authorized and there is no supervision of dumping (Brunner, et al., 1971, cited in University of Oklahoma, 1983). Virtually every type of solid waste has been deposited in open dumps—abandoned tires and automobiles, old furniture and kitchen appliances, industrial and commercial wastes, agricultural byproducts, trees, vegetation, demolition and construction wastes, and various household wastes—and virtually every type of topography has been used for this dumping. Open dumps are frequently burning dumps as well, whether resulting from deposition of smoldering wastes, spontaneous ignition, or intentional ignition to reduce volume.

EPA listed approximately 1,950 open dumps in its inventory (EPA, 1982a); in a more recent survey by *Waste Age* (Petersen, 1983) the figure is 2,396. Because these two estimates include only the open dumps known to regulatory authorities, they are minimum estimates. It is not possible at this time to generate any reasonable estimate of the amount of material disposed of in open dumps annually.

6. Residential (Local) Disposal

A variety of hazardous and toxic substances are commonly found in household wastes. These wastes often are disposed of in specific facilities designed for waste disposal or discharge (e.g., municipal landfills). However, they also are disposed of indiscriminately, without supervision, in gutters, sewers, storm drains, and backyard burning pits—these practices constitute residential (or local) disposal. The pattern of residential disposal follows population density and distribution.

Household wastes are composed of a wide range of product materials: pesticides; paint products (e.g., oil-based paints, thinners, removers, and wood preservatives); cleaners (e.g., drain cleaners, furniture polish, air fresheners, floor wax, disinfectants, chlorine bleaches, degreasers, nail polish removers, spot removers, oven cleaners, drycleaning fluids, detergents, aerosol sprays, rug cleaners, and shoe care products); automobile products (e.g., antifreeze, waste oil, and brake fluid); asphalt and roofing tar; and batteries.

Development of Estimates of Numbers and Amounts

Little quantitative information is available about where most household substances are ultimately disposed of, primarily because household wastes do not usually come under Federal and State regulations and are not investigated systematically. A few community and government agencies have attempted to tackle this problem; among the most noteworthy are efforts of the Water Quality Division of Seattle (Ridgley, et al., 1982), the Metropolitan Area Planning Council of Boston (MAPC, 1982), and community grassroots collection campaigns like the ones in Lexington, MA (Watson, 1983) and Seattle (Ridgley, et al., 1982).

Some quantitative information is available. Approximately 30,000 tons of household cleaners were used by the 1.2 million people in King County (Seattle Metropolitan Area) in 1980 (Ridgley, et al., 1982). The city of Tacoma, WA (population 150,000), uses 264 tons of liquid household cleaners, 72 tons of toilet bowl cleaners, and 66 tons of motor oil per year (based on Tacoma-Pierce County Health Department, no date). If the rates of use of household cleaners are extrapolated to the entire United States, then approximately 0.4-5.6 million tons of such cleaners are used annually.

Over 90 percent of households in the United States use pesticides in the home, garden, and/or yard (Savage, et al., 1980, cited in Ridgley, et al., 1982). It is estimated that 5-10 percent of *all* pesticides used are applied in this manner (Seiber, 1981; EPA, 1980a). The lower percentage (i.e., 5 percent) is derived as follows: at least 80 million pounds of pesticides were used in homes and gardens in 1980 (EPA, 1980b), and this figure is about 5 percent of the 1.5 billion pounds of pesticides produced annually (see *Pesticide Applications* below). The mean rate of pesticide applications by households has been estimated to be 5.3-10.6 pounds per acre, and urban soils often have higher levels of pesticide residues than do croplands (vom Runker, et al., cited in Grier, 1981-82).

Potential for Groundwater Contamination

Residential disposal has great potential for contaminating groundwater. Uncontrolled burning can cause toxic fumes, and the hazardous materials concentrated in ashes can be leached into groundwater. Spilled oil, pesticides, and fertilizers are washed off driveways, yards, and gardens into storm drains and local streams. Toxic wastes are often poured down household drains; the result is corroded pipes (which can cause higher heavy-metal concentrations in sewage), septic tank malfunctions, pipeline leakage (including from sewers), and interference with the operation of municipal sewage treatment facilities. All these negative impacts can lead to groundwater contamination. In addition, household hazardous wastes that are deposited in specific facilities designed for waste disposal (e.g., landfills) have the potential to contaminate groundwater.

7. Surface Impoundments

Surface impoundments are used by both industries and municipalities for the retention, treatment, and/or disposal of both hazardous and non-hazardous liquid wastes. They can be either natural depressions or artificial holding areas (e.g., excavations or dikes); the term "pit" is commonly applied to a small impoundment used by industries, municipalities, agricultural operations, or households for special purposes (e.g., farm waste storage, industrial wastewater storage, and sludge disposal). The wastewater in impoundments is treated by chemical coagulation and precipitation, pH adjustment, biological oxidation, separation of suspended solids from liquids, and reduction in water temperature. Surface impoundments operate under one of two schemes: discharging and non-discharging. Discharging impoundments are designed to release their liquid contents either periodically or continuously into streams, lakes, bays, or the ocean. Non-discharging impoundments lose their liquid by evaporation and/or seepage. Impoundments that rely on evaporation are usually lined with low-permeability materials to prevent seepage and are most effective in arid areas.

Surface impoundments vary in shape, and they are operated individually or as a series (EPA, 1982b). They range in depth from 2-3 feet (0.6-0.9 m) to more than 30 feet (9 m) below the land surface, and their surface area varies from a few tenths of an acre to thousands of acres. Agricultural, municipal, industrial, and oil and gas production impoundments are generally small—90 percent or more are under 5 acres (EPA, 1982b). The largest impoundments reported to EPA for the agricultural, municipal, and oil and gas production categories were 665, 850, and 79 acres, respectively. Industrial impoundments, in contrast, can be quite large—20 impoundments larger than 1,000 acres were reported to EPA, with one covering 5,300 acres. The size of mining impoundments depends on the type of mining. Ninety percent of coal mine impoundments are less than 5 acres; the largest is 293 acres. However, the surface impoundments of only 58 percent of metal mines and 48 percent of other non-metal mines are less than 5 acres; the largest in these categories are 1,990 and 1,229 acres, respectively.

Surface impoundments are located in proximity to the activity creating the liquid wastes. Thus agricultural impoundments tend to be concentrated in the Central, Midwestern, and Southeastern United States. Municipal impoundments are associated with population centers and are most common in the East. Industrial impoundments are most common in the East and Northeast, and along the Great Lakes and the west coast. Oil and gas impoundments are concentrated in Texas, Oklahoma, and Louisiana. Mining impoundments are concentrated in coal mining areas (e.g., Pennsylvania, Ohio, and West Virginia).

Development of Estimates of Numbers

As part of implementing the Safe Drinking Water Act (1442(a)(8)(C)), EPA initiated a nationwide Surface Impoundment Assessment in 1978 (EPA, 1978, 1982b). Most of the available information about surface impoundments is the result of these efforts. Unless otherwise stated, the discussion that follows is based on the report issued in 1982.

A total of 180,973 impoundments was located by EPA: 27,912 industrial, 37,185 municipal, 19,437 agricultural, 25,038 mining, 65,488 oil and gas brine pit, and 5,913 other impoundments. The most important industrial users of impoundments are the food processing and chemical industries, each with more than 4,000 known impoundments. Other heavy industrial uses (i.e., using more than 1,000 impoundments) are for petroleum refineries; power plants; paper products; stone, clay, and glass products; primary metals; and fabricated metals. Municipal impoundments are located at landfills and water and waste treatment facilities; about 33,000 were at sewage treatment plants. Agricultural impoundments are used in crop production, animal husbandry, and other farming operations; most of them are associated with feedlot waste operations. Mining impoundments are associated with ore extraction and treatment, washing, and sorting processes. All of the numbers cited are thought by EPA to be conservative, especially for industry and for oil and gas brine pits—the estimate for oil and gas impoundments does not include burn pits, cuttings pits, or mud pits. Further, at least 1,078 impoundments regulated under RCRA were used for the storage, treatment, or disposal of hazardous wastes in 1981 (Dietz, et al., 1984). Whether these facilities are included in the total of 180,973 is not known.

Development of Estimates of Amounts

The amount of liquid wastes disposed of in surface impoundments can be estimated in a variety of ways. Approximately 50 billion gallons of liquid wastes per day are deposited in industrial surface impoundments in the United States (EPA, 1980, cited in U.S. House of Representatives, 1980), and approximately 82 billion gallons per day are deposited in all types of impoundments (The Conservation Foundation, 1982). The amount of wastes actually contributing to groundwater contamination depends on leakage from the impoundments; the commonly used leakage rate of 6 percent (Miller, 1980) is used here. Accordingly, approximately 1,095 billion gallons per year (bgy) and 1,800 bgy of liquid waste leachate from industrial and from all types of surface impoundments, respectively, are available for entry into groundwater (i.e., 50 billion gallons per day × 365 days per year × 0.06 for industry; 82 billion gallons per day × 365 days per year × 0.06 for all types).

The amount of liquid wastes deposited in municipal impoundments can also be estimated. EPA (1978) calculated that 6,300 municipal impoundments had a total flow of 4.2 billion gallons per day. Using these figures to obtain a flow rate per impoundment and applying the 6 percent leakage rate yields an estimate of 540 bgy for the 37,185 municipal impoundments found by EPA. A second estimate, of 705 bgy for municipal impoundments, can be derived by subtracting the 1,095 industrial bgy from the 1,800 total bgy; this figure is a maximum estimate because it includes all but industrial impoundments.

Brine pits are almost universally banned in the United States, but they were the major means of brine disposal prior to the 1970s. Current disposal rates for brine pits cannot be estimated because they are not monitored.

The metals mining industry puts approximately 250 million tons of tailings into ponds each year.

Thus estimates can be developed for the amount of liquid wastes converted into potential leachate for industrial, municipal, and mining impoundments and for all impoundments together. The latter figure, 1,800 bgy, is in marked contrast with Miller's (1980) estimate of 161 bgy. Miller's estimate for liquid wastes consists of separate estimates of 100 bgy from industrial treatment lagoons, 43 bgy from brine pits and basins, and 18 bgy from municipal treatment lagoons. Miller's estimate is almost certainly much too low, but the accuracy of the 1,800 bgy estimate is difficult to evaluate.

The above estimates refer to hazardous and non-hazardous liquid wastes in *all* surface impoundments. Quantitative information is also available regarding the deposition of hazardous liquid wastes (which may include non-hazardous liquid wastes) into surface impoundments regulated under RCRA (Dietz, et al., 1984). In 1981, 5.1 billion gallons of hazardous wastes were disposed of, 16.6 billion gallons were treated, and 14.1 billion gallons were stored in these surface impoundments (Dietz, et al., 1984).

Potential for Groundwater Contamination

In terms of their numbers and the amounts of wastes associated with them, waste impoundments (including pits, ponds, and lagoons) may be one of the biggest threats to groundwater. More than 23,000 cases of groundwater contamination have been documented in Texas alone, primarily resulting from brine pits (EPA, 1977a). In Colorado, 37 percent of the known impoundments pose an "actual threat" to groundwater and over 53 percent pose a "potential threat" (*The Groundwater Newsletter*, 1983a). The potential for health effects is highly variable and depends on public use of affected aquifers; most mining, oil and gas, and agricultural sites are located in remote areas and thus are likely to have a low potential for affecting large numbers of people if they should contaminate groundwater, relative to other types of impoundments. However, many impoundments are located near concentrations of people, and almost 87 percent are located over aquifers currently used as a source of drinking water (EPA, 1982b). About 50 percent are located over unsaturated and very permeable zones (EPA, 1982b).

Contamination of groundwater by a particular impoundment will depend on soil permeability, depth to the water table, rates of evaporation and precipitation (including potential for overflow), geochemical characteristics of the soils (e.g., ion exchange and absorption), chemical composition and volume of the wastes, and other factors (EPA, 1978). For example, heavy metal movement depends on incorporation of the metals into the bottom of the impoundments, leakage rates, and interactions of each metal with different underlying soils.

The contamination potential may be reduced if natural or artificial liners are located beneath the impoundment. The 1982 EPA survey indicated that only about 15-17 percent of all impoundments had liners, with a range of 10 percent for oil and gas impoundments to 28 percent for industrial impoundments. More recent data presented by EPA (*Inside EPA*, 1983d) indicate that 62 percent of all impoundments have at least a single liner; less than 22 percent have a double liner. In some States (e.g., California, Idaho, Illinois, Kentucky, Nevada, Oregon, and Pennsylvania) use of liners in all impoundment categories is widespread; in other States, use is widespread in only one or two impoundment categories.

EPA analyzed 416 case studies of groundwater contamination from impoundments and found that in 78.7 percent of the cases the contamination was caused by direct seepage, in 10.1 percent by dike failure or overflow, in 7.6 percent by liner failure, in 1.6 percent by catastrophic collapse, and in 2.0 percent by other causes. EPA also evaluated the impoundments' potential to contaminate groundwater, water wells, and surface water as shown in table A.5.1. Overall, 93 percent were judged to have intermediate or high potential for groundwater contamination.

8. and 9. Waste Tailings and Waste Piles

Mining operations generate two basic types of solid wastes—spoil piles and tailings. Spoil piles are generally disturbed soil and overburden from surface mining or waste rock from underground mining operations (Miller, 1980). Tailings are the solid wastes from the on-site operations of cleaning and extracting ores. Both types of solid wastes are often piled on the land surface or used as fill in topographic depressions confined by earthen dams (University of Oklahoma, 1983). They

Table A.5.1.—Contamination Potential of Surface Impoundments[a]

Impoundment category	High potential to contaminate groundwater	Potential to contaminate water wells	Potential to contaminate surface wells
Municipal	41 percent	27 percent	58 percent
Industrial	39 percent	29 percent	56 percent
Agricultural	26 percent	28 percent	61 percent
Mining	25 percent	17 percent	64 percent
Oil and gas	8 percent	17 percent	68 percent

[a] Data for "high potential to contaminate groundwater" are independent of data for other two columns.

SOURCE: EPA, 1982b.

are discussed together in this section because it is not always clear in the literature which source category is being referred to.

Development of Estimates of Numbers and Amounts

Metal and non-metal mines (excluding coal mines) produced 1.5 billion tons of waste rock in 1972 (EPA, 1977a); estimates of known amounts of tailings range from 215 million tons at both inactive and active uranium mining sites (Thomson, et al., 1983) to 250 million tons deposited in ponds annually by the metal mining industry (Miller, 1980). These figures total 1.72-1.75 billion tons, approximately 86 percent of which is in the form of waste piles (i.e., 1.5 billion tons of waste rock in 1.75 billion tons of waste material).

Approximately 2.3 billion tons of *total* waste material, including radioactive tailings, are generated annually by mining operations (EPA, 1981b; OTA, 1983a); this figure apparently includes both waste piles and tailings (both radioactive and non-radioactive). If the 86 percent figure is applied to the total of 2.3 billion tons, approximately 2.0 billion tons are in waste piles and 0.3 billion tons are in the form of tailings. The proportion of tailings may increase in the future; for example, the amount of active uranium mill tailings is projected to increase to 1.0-1.9 billion tons by the year 2000 (Landa, 1980; also see *Radioactive Disposal Sites*, below).

Hazardous waste piles may also be generated by industrial operations. Hazardous waste piles at 174 facilities contained an estimated 0.39 billion gallons in 1981 (Dietz, et al., 1984). In view of the fact that these waste sites include only those regulated under Federal laws, the number of sites and amount of material probably represent the lower bounds.

Potential for Groundwater Contamination

In terms of their numbers, amounts of material, and nature of their contents, waste piles and tailings are among the major potential sources of groundwater contamination, especially from uranium, copper, and coal mining (Thomson, et al., 1983; Pye, et al., 1983; Johnson, 1983; Landa, 1980). Approximately one-third of active tailings piles have contaminated nearby shallow aquifers (EPA, 1983d).

Precipitation percolating through spoil piles and tailings carries soluble substances (e.g., arsenic, sulfuric acid, copper, selenium, and molybdenum) and radioactive wastes (e.g., isotopes of uranium, thorium, and radium, including radium-226 which has a half-life of 1,620 years) to the underlying water table (University of Oklahoma, 1983; Thomson, et al., 1983). Arsenic, selenium, lead, manganese, molybdenum, and vanadium have been found in groundwater in seven States at distances of up to 1.5 miles from tailings piles and at concentrations above Federal or State limits (EPA, 1983e).

The most serious side-effects are associated with sulfide minerals (Koch, et al., 1982). Sulfuric acid is often generated from coal mining spoils by the oxidation of the sulfides in the coal; subsequent percolation into the water table results in acidic groundwater. Other minerals (e.g., lead, silver, zinc, molybdenum, nickel, and copper) are commonly found as sulfide ores; mining these minerals can also lead to the production of sulfuric acid (Koch, et al., 1982). In addition, the acid can dissolve other contaminants adsorbed on the soil into groundwater.

Impacts on groundwater quality depend on several factors: the location, size, and configuration of piles and tailings; the composition of piles and tailings; the climate (e.g., rate of precipitation); hydrogeological characteristics; and the control technology employed. Groundwater protection is not provided at many existing tailings disposal sites (Thomson, et al., 1983).

In some cases, certain factors can reduce the potential for groundwater contamination or the numbers of people affected. For example, many mining and smelting operations occur in arid or remote regions (e.g., for copper and uranium; EPA 1983e; Koch, et al., 1982; Thomson, et al., 1983). Low-grade ore piles (e.g., copper) can be subjected to controlled leaching and the runoff collected for reprocessing (Koch, et al., 1982). Further, a low pH is often rapidly neutralized as the flow leaves the tailings (Thomson, et al., 1983).

10. Materials Stockpiles

Development of Estimates of Numbers and Amounts

Very little information has been obtained regarding either the numbers or the amounts of materials in stockpiles in the United States. Approximately 3.4 billion tons of various materials (e.g., coal, sand and gravel, crushed stone, copper ore, iron ore, uranium ore, potash, titanium, phosphate rock, and gypsum) were produced in 1979 (Koch, et al., 1982). Stockpile size is probably proportional to production in most cases; however, data comparing production and stockpiles are available only for coal, iron ore, phosphate rock, titanium, and gypsum (Koch, et al., 1982). Stockpiles represent approximately 20-25 percent of production for coal, iron ore, and gypsum (annual production is more than 700 million tons of coal, more than 240 million tons of iron ore, and about 15 million tons of gypsum) and approximately 5-8 percent of production for phosphate rock and titanium (annual production is about 191 million and 20 million tons, respectively).

For a preliminary estimate of the total volume held by materials stockpiles, assume that 20 percent of total materials production is stored in stockpiles. The choice of this percentage is based on an aggregation of the above percentages for the individual minerals and is weighted toward the higher figures because of the larger tonnages produced for those minerals. Given the total annual materials production of 3.4 billion tons, approximately 700 million tons per year are stockpiled. Reliability of the estimate is low but should be within an order of magnitude.

Some descriptive information is available for coal production and stockpiling. Approximately 780 million tons of coal were produced in 1979. Coal is stored outdoors primarily by electric utilities, coke plants, and industrial users; the average coal pile contained 95,000 metric tons and was 5.8 meters high. Coal stockpiles at utilities were estimated at 185 million tons in 1980 (Koch, et al., 1982). Substances present in coal piles include aluminum, iron, calcium, magnesium, sodium, potassium, manganese, sulfur, and phosphate, with trace amounts of arsenic, cadmium, mercury, lead, zinc, uranium, copper, and cobalt (Koch, et al., 1982).

Potential for Groundwater Contamination

Problems associated with materials stockpiles are much the same as those associated with waste piles and tailings (see *Waste Tailings and Waste Piles*, above); the major difference is that materials stockpiles are not wastes. But for all, the concern is the ultimate disposition of the soluble substances. Water percolating through stockpiles can carry soluble substances to the groundwater. Chemical reactions within coal piles, in particular, can produce sulfuric acid and ferric sulfate, which can then be carried down to the groundwater by precipitation percolating through the pile.

11. Graveyards

Decomposing bodies in graveyards produce fluids that can leak to underlying groundwater, especially if nonleakproof caskets are used.

The potential for graveyards to contaminate groundwater depends on several factors. Groundwater contamination is primarily a function of soils and depth to groundwater. Areas with high rainfall and high underlying water tables are most vulnerable to contamination from graveyards. Studies of individual cemeteries indicate that, in all cases, soil contamination occurred in immediate proximity to the graves but not all graveyards actually contaminated groundwater (Bouwer, 1978). Although the contamination potential cannot be accurately quantified, the magnitude of contamination appears to be highly localized and is probably much less than that from other sources.

12. Animal Burial

Animal burial procedures have become increasingly sophisticated. Mass burial—less common than individual burials—occurs near large concentrations of livestock and in local landfills or open dumps. Individual burials are most likely to take place within sections of municipal landfills or in residential backyards.

There are no data to assess the potential contribution of this source to groundwater contamination. It is highly site-specific and depends on disposal practices, the surface and subsurface hydrology, the proximity of the site to water sources, the nature and amount of the disposed material, and the cause of death.

13. Aboveground Storage Tanks

Aboveground storage tanks are used in industrial, commercial, and agricultural operations and at individual residences for a large variety of chemicals. No systematic information is available regarding numbers, sizes, and locations of these tanks or of the chemicals stored in them.

14. Underground Storage Tanks

Underground storage tanks are used by industries, commercial establishments, and individual residences for storage and treatment of products or raw materials, waste storage and treatment, and piping systems (San Francisco Bay Regional Water Quality Control Board, 1983; University of Oklahoma, 1983). Little information is available regarding treatment tanks; unless otherwise indicated, the discussion below refers to storage tanks. In addition, information about steel and fiberglass tanks will be distinguished whenever possible.

Industrial use is primarily for fuel storage but also for storage of a wide range of other substances including acids, metals, industrial solvents, technical grade chemicals, and chemical wastes (San Francisco Bay Regional Water Quality Control Board, 1983; California Assembly Office of Research, 1983). Commercial businesses (e.g., airports, corporations with car fleets, recyclers, farmers, and trucking industries) and individual homeowners use underground storage almost exclusively for fuel storage. Underground storage tanks are widespread throughout the country; gasoline storage tanks are concentrated in areas with high population density (and therefore with high automobile usage).

Development of Estimates of Numbers

The most numerous underground storage tanks are those used for gasoline at service stations and for fuel oil at residences. Based on the number of independent and major service stations in the United States (Lundberg, 1982) and on the average number of underground tanks per station, approximately 1.2 million *steel* underground tanks are found at service stations alone (Rogers, 1983).[3] Approximately 100,000 *fiberglass* tanks also are used for underground storage of petroleum products and several thousand are used for non-petroleum products (Hammond, 1983).

Many other underground storage tanks, both known and unknown (and both active and abandoned), are used for petroleum and non-petroleum products throughout the country (Dalton, 1983; Rogers, 1983; White, 1983). The 1.2 million steel tanks at service stations may represent only one-fourth to one-third of the underground steel storage tanks for all products, the remainder being used by trucking companies, corporations, farmers, government agencies, and others (Rogers, 1983; White, 1983). White (1983) estimates that about 25 percent of all steel storage tanks are used by the petroleum industry (half of them by major producers and half by independent retailers), 25 percent by farmers, 5-6 percent by government agencies, and the remainder by various users. Note that the estimate that one-fourth to one-third of all steel underground tanks are used for petroleum may be too low for two major reasons. First, it seems to be based on data from Santa Clara County, CA, where the number of industrial chemical solvent storage tanks may be higher, and the relative number of tanks used for petroleum lower, than is typical of most of the country because of the number of high-technology industrial firms in Santa Clara County (Donovan, 1983). Second, approximately 60 percent of the 40,000 tanks produced annually for the last 5 years (28,000 steel and 12,000 fiberglass) have been installed at service stations (Donovan, 1983).

OTA's study assumes that the number of steel tanks at service stations represents about one-half of *all* steel tanks. This figure is a compromise between the one-fourth to one-third and the 60 percent, weighted toward the latter because it is based on more reliable data. Using this assumption yields an estimate of 2.4 million steel underground tanks in the United States. The additional fiberglass tanks used for storing petroleum and non-petroleum products bring the total estimate to 2.5 million underground storage tanks for all non-hazardous products.

There were at least 2,031 hazardous waste storage tanks and treatment tanks regulated under RCRA in 1981 (Dietz, et al., 1984); this figure does not include hazardous waste tanks operating under NPDES permits. Just how many of these are underground or aboveground is not known, but they are considered as an underground source in this analysis.

Development of Estimates of Amounts

It is very difficult to obtain an accurate estimate of the amount of material stored in underground storage tanks, but one approach involves using the average capacity of known tanks. The average service station underground steel tank held 4,000-6,000 gallons in the 1950s and now holds about 10,000 gallons; the largest registered steel tank has a capacity of 50,000 gallons (Donovan, 1983). The average capacity of fiberglass tanks is also about 10,000 gallons (Steel Tank Institute, 1983). Assuming an average 10,000-gallon capacity for underground tanks, the 2.5 million underground storage tanks have an estimated capacity of 25 billion gallons. The hazardous waste storage tanks and treatment tanks contain an estimated 13.8 billion gallons (Dietz, et al., 1984); this figure does not include hazardous wastewaters stored in tanks for less than 90 days or in tanks operated under NPDES permits.

Design, Operation, and Maintenance Characteristics

The installation and use of underground storage tanks are often not regulated. Most often the only regulations are local requirements for construction and installation, but even in these cases follow-up or periodic checks are rarely required to determine whether leaks have developed. Cathodic protection for steel tanks was seldom provided until recently; most tanks more than 15 years old are unprotected (Hammond, 1983).

There are no design requirements at the Federal level or in many States for storage facilities that might pose a threat to groundwater. At a minimum, design requirements should address (API, 1976): 1) tank construction—e.g., to ensure compatibility with stored substances and with local soil conditions; 2) reserve capacity; 3) safety devices—e.g., cutoff devices; and 4) inspection. The typical design life of tanks varies from 15-20 years for unprotected steel tanks and is highly dependent on environmental conditions. Leaks typically begin within 7 years of installation in humid areas or if tanks are in contact with salt-water, but they may not occur for more than 30 years in arid areas (Feliciano, 1984). No information was available about the typical design life of protected steel tanks but presumably it is more than 20 years. The design life of fiberglass tanks is estimated at 40-50 years (Hammond, 1983); this figure is only a prediction—fiberglass tanks have been used commonly only since 1970, and the oldest one that has been tested for leaks is 13 years old.

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[3] This is a generally accepted figure and is cited by EPA (*Inside EPA*, 1983c) and by the Steel Tank Institute both in publications (e.g., Steel Tank Institute, 1983) and personal communications. Feliciano (1984) estimated that approximately 1.4 million underground tanks were used for storing gasoline.

The Pollution Liability Insurance Association no longer insures steel tanks more than 20 years old unless they meet stringent testing requirements (Morrison, 1983). Fiberglass tanks are warranted for up to 30 years (Hammond, 1983), but the Underwriters Laboratories insurance standards for fiberglass tanks do not cover alcohol blends (e.g., ethanol; Steel Tank Institute, 1983).

Potential for Groundwater Contamination

Underground storage tanks are known to have caused many cases of groundwater contamination (e.g., San Francisco Bay Regional Water Quality Control Board, 1983). In particular, old corroded gasoline storage tanks are frequently cited as sources of contamination (University of Oklahoma, 1983). As many as 77 percent of underground steel tanks may be affected by point corrosion (Rogers, no date). Such corrosion can be caused by impurities in the backfill, faulty installation involving surface abrasions and failure to remove shoring, and certain soil conditions (e.g., involving acidity, electrical resistance, presence or absence of sulfides, or moisture content).

Many companies have installed new tanks near old ones. When they do, a new tank often acts as a "sacrificial anode" (i.e., metallic ions flow from the new tank to the old tank) and it rusts faster (Dalton, 1983). In addition, dispensing pumps can develop leaks in couplings and hoses, and delivery lines can corrode or break (Dalton, 1983). Although new underground tanks are usually coated with a protective or corrosion-resistant material if they are steel or are made from relatively corrosion-resistant materials (e.g., fiberglass), they are still subject to corrosion-induced leakage. Fiberglass tanks can crack if installed incorrectly, and the polyester resins in fiberglass may be weakened by some alcohol-blend gasolines (Feliciano, 1984).

Tank age may be a principal factor in groundwater contamination (Rogers, 1983). Leaks have been observed in underground steel tanks aged 5-45 years but about one-third occur in tanks aged 15 years or less (Rogers, 1983). In New York, 60 percent of the leaks are in tanks older than 16 years, and 86 percent are in tanks more than 10 years old (New York State Department of Environmental Conservation, 1982). Many steel tanks in the United States are now in their mid-teens or older; the National Oil Jobbers Council estimates that nearly one-third are more than 16 years old (cited in Larson, 1983). Rogers (1983) directed a study of 46,000 steel tanks owned by major oil and gas producers and found the following age composition: 4 percent less than 5 years, 20-23 percent between 5 and 10 years, 27 percent between 10 and 15 years, 21 percent between 15 and 20 years, and approximately 25 percent over 20 years. The age structure of this sample is probably younger than if a comparable sample had been taken from independent retailers because the major producers have recognized the potential for older tanks to leak and in the 1970s began to replace their older tanks (Donovan, 1983).

Rogers developed a model for predicting where leaks will occur, based on tank age and local soil conditions; it can also be used to estimate the number of leaking tanks. The leakage rate is assumed to increase as the tank population ages. Results from the model have been tested for approximately 10,000 tanks. Based on the age composition of the tanks and projected annual rates, Rogers estimated that about 50,000 tanks were leaking in 1982 and approximately 90,000-100,000 tanks would leak in 1983. This figure could be low because Rogers also estimated that approximately 25-30 percent of all steel tanks probably leak. If so, up to 720,000 underground steel tanks could be leaking (applying the upper figure of 30 percent to the 2.4 million steel tanks). EPA estimates that up to 240,000 tanks may be leaking and that the figure may increase to 75 percent of the total in the next 5 years (*Inside EPA*, 1983c).

Whether a leak contaminates groundwater is highly dependent on site-specific conditions including the concentration of the contaminant and the flow rate of the particular leak. For example, not all leaks at service stations contaminate groundwater. In fact, Rogers (1983) estimates that 85 percent of underground tank leaks at service stations do not go beyond the station boundary (because of the small amount of leakage or early detection) and do not contaminate groundwater; these incidents have typically cost $20,000-$30,000 to clean up. Another 10 percent of the leaks are estimated to travel beyond service station boundaries but are detected before they contaminate groundwater; typical costs of these operations are $150,000. However, 5 percent of the leaks *do* contaminate groundwater, with typical cleanup costs of $2.5-$5 million and as high as $11 million.

15. Containers

Containers are storage barrels and drums for various waste and non-waste products. They can be moved around with relative ease, and although they may be buried, they are not specifically designed to be. Very little information is available about containers because they are not covered by any Federal water quality regulations. In 1981, about 3,577 facilities used containers for the storage of 0.16 billion gallons of hazardous wastes (Dietz, et al., 1984.) These figures are only for containers regulated under RCRA; actual numbers and amounts could be considerably higher.

16. Open Burning and Detonation Sites

Very little information is available on this source. Although there are probably many cases of waste materials burned in backyards or at landfills, these cases are classified here under the open dump, residential disposal, or landfill sources. Detonation sites are more structured (i.e., designed) operations; burning grounds could be either structured or unstructured. In 1981, 240 facilities regulated under RCRA incinerated 0.45 billion gallons of hazardous wastes (Dietz, et al., 1984).

The Department of Defense operates a number of burning grounds and ammunition detonation sites. Twelve such sites have been surveyed at Army installations, and TNT (and other hydrocarbons) and heavy metals (e.g., cadmium and chromium) have been detected in soil and in groundwater (U.S. Army Toxic and Hazardous Materials Agency, 1983). Several commercial and industrial sites listed on the National Priorities List by EPA (under CERCLA) have had fires or were operated as burning sites; groundwater contamination has been detected at all these sites.

17. Radioactive Disposal Sites

Radioactive materials arise from the nuclear fuel cycle, commercial and industrial products and wastes, and natural sources. They may have long half-lives, and they can migrate with no visible evidence. Natural radiation (e.g., radon-222) occurs throughout the United States, with the highest concentrations in granite formations (e.g., in Maine) and gypsum (e.g., in Florida).

Five basic types of waste products are produced in the development and generation of nuclear fuel and radioactive materials (DOE, 1983):

1. *Spent fuel* is the discharged irradiated fuel resulting from nuclear powerplant operations. It includes cesium-137 (half-life 28 years), strontium-90 (half-life 33 years), and cobalt-60 (half-life 6 years). Wastes containing these isotopes may need several hundred years or more to decay to low levels of radioactivity, with some estimates ranging as high as 100,000 years (University of Oklahoma, 1983).
2. *High-level wastes* are from the initial processing of irradiated reactor fuels. They are extremely radioactive, must be stored in specially constructed facilities, and eventually are either reprocessed or transferred to the Federal Government for long-term storage or permanent disposal (DOE, 1983).
3. *Transuranic* wastes, defined on the basis of specific radioactive criteria (DOE, 1983), result primarily from fuel reprocessing and from the manufacture of plutonium-containing products.
4. *Low-level wastes* are generated in liquid, gaseous, and solid forms and consist of a wide range of materials having generally low but potentially hazardous amounts of radiation (this category excludes uranium mill tailings). Low-level radioactive wastes are generated by nuclear reactors used for power production, weapons production, research (e.g., at universities and hospitals), and commercial products or activities (e.g., at hospitals). They can be in the form of discarded equipment, assorted refuse, and materials from decontamination facilities. They are either diluted until no longer classified as radioactive, disposed of indiscriminately, or shipped to approved low-level disposal sites.
5. *Uranium mill tailings* are the earthen residues left after the uranium is extracted from ores. Uranium refining also generates small amounts of solid, or semi-solid, low-level radioactive waste. Although the chemistry of the wastes varies among refineries, radium-226, thorium-230, and uranium-238 are usually present in small but significant concentrations. Disposal has commonly occurred in shallow burial grounds located near the refineries. (The waste rock associated with these radionuclides is discussed under *Waste Tailings and Waste Piles*, above).

Development of Estimates of Numbers

Prior to the mid-1970s, low-level radioactive wastes were routinely packaged and shipped to commercial shallow nuclear waste burial sites. Six commercial sites were in operation, but three have been closed and two are accepting severely reduced volumes; the major remaining site is in the State of Washington. The Departments of Energy and Defense also maintain 22 sites for low-level waste disposal (DOE, 1983). High-level radioactive wastes are deposited at four regulated sites (Hanford, WA; Idaho Falls, ID; Aiken, SC; West Valley, NY) or are contained on-site at their place of generation (see OTA, 1982). Seven sites are used for transuranic waste disposal. Commercial spent fuel is usually stored at reactor sites or at two specific disposal sites.

Because different types of wastes are sometimes sent to the same site, the number of disposal sites is actually less than the total of 38 in the above figures. Although recent legislation has called for State cooperation in site development for low-level radioactive waste disposal, commercial generators of low-level wastes are likely to be faced with possession of these wastes for some time. Remedial actions at inactive mill tailings sites are to be conducted by DOE under the Uranium Mill Tailings Radiation Control Act, but these actions have not yet begun (DOE, 1983; see ch. 9).

Development of Estimates of Radioactive Waste Production

A total of 4.80 million cubic yards of radioactive wastes was contained at various storage sites as of December 31, 1982 (DOE, 1983). This total was distributed as follows: 0.41 million cubic yards of high-level wastes, 0.48 million cubic yards of transuranic wastes, 3.78 million cubic yards of low-level wastes, and approximately 7,400 tons of spent fuel (the first three figures are based on DOE, 1983; the last on Hileman, 1982). Uranium mill tailings are discussed under *Waste Tailings and Waste Piles*, above.

Potential for Groundwater Contamination

Radioactivity is a major threat to groundwater because of the longevity of isotopes and their ability to migrate unnoticed. Much debate centers on the efficacy of waste disposal burial methods over time; for example, disposal containers are often deposited in or above shallow water tables. Some isotopes enter groundwater from radioactive wastes, but other isotopes are present because of the leaching of natural geologic substances (e.g., gypsum). It is estimated that 10-30 square miles of land are underlain by groundwater contaminated beyond potable use by radioactive wastes (USGS, 1983).

Numerous radionuclides have been detected in groundwater as shown in table A.5.2. These radionuclides emit three types of radiation: alpha (α), beta (β), and gamma (γ) (League of Women Voters Education Fund, 1980). Alpha radiation has the least power to penetrate skin, but it can cause severe tissue and organ damage if it enters the body through ingestion of contaminated drinking water or food or through inhalation. Beta radiation is more penetrating, but it also is most serious when ingested or inhaled. Gamma radiation has the greatest power to penetrate skin and usually is associated with beta radiation; it too can damage critical organs.

Table A.5.2.—Categorization of Known and Potential Radionuclides in Groundwater by Mode of Decay

Radionuclide[a]	α	β	β and γ, combined	γ
Antimony-125			X	
Barium-140			X	
Cesium-134			X	
*Cesium-137			X	
*Chromium-51				X
*Cobalt-60			X	
Iodine-129			X	
*Iodine-131			X	
*Iron-59			X	
*Lead-210			X	
*Phosphorus-32		X		
*Plutonium-238	X			
*Plutonium-243			X	
*Radium-226	X			
*Radium-228		X		
Ruthenium-103			X	
*Ruthenium-106		X		
*Scandium-46			X	
Strontium-89		X		
*Strontium-90		X		
Strontium-131			X	
*Thorium-270	X			
*Tritium		X		
Uranium-230	X			
*Uranium-238	X			
*Zinc-65			X	
*Zirconium-95			X	

[a] Radionuclides marked with an asterisk are known to have contaminated groundwater and are documented by at least two of the listed sources.
Alpha (α), beta (β), and gamma (γ) radiation are discussed in the text.

SOURCE: Woodward-Clyde Consultants, Inc., 1983; University of Oklahoma, 1983, Environ Corp., 1983.

18. Pipelines

Pipelines are used to transport, collect, and/or distribute both wastes and non-waste products. The wastes are primarily municipal sewage, most often located in densely populated areas. The primary non-wastes are petroleum products and natural gas, but ammonia, coal, sulfur, and anhydrous ammonia are also transported (University of Oklahoma, 1983). Non-waste pipelines are located throughout the Nation; maps of major pipeline networks are available from the Federal Energy Administration (University of Oklahoma, 1983).

Development of Estimates of Numbers and Amounts

Approximately 175,000 miles of pipeline carrying 9.63 billion bbls of petroleum products per year were in operation in the United States in 1976 (Pye, et al., 1983). Information presented in Miller (1980) indicates that approximately 700,000 miles of sewer pipeline were in use in 1980. In 1978, 154 million people were served by sewer pipelines (U.S. Department of Commerce, 1981). Assuming an average sewage flow of 100 gallons per day per person (Miller, 1980), approximately 5.6 trillion gallons of sewage were transported by sewer pipelines in 1978.

Potential for Groundwater Contamination

Although pipelines are designed to retain their contents and thus pose no threat to groundwater, in reality they have a contamination potential through leakage. The major causes of leaks are ruptures, external and internal corrosion, incorrect operating procedures, and defective welds or pipes. In 1981, these causes accounted for 41 percent, 22 percent, 7 percent, and 6 percent of all reported leaks, respectively (DOT, 1981). Other causes were surges (e.g., floods) of fluid in pipelines, breakage or heaving of lines by tree roots, earthquakes, loss of foundation support, and rupture due to other loads. Miller (1980) estimated that leakage from sewer pipelines was around 5 percent; if it is, approximately 280 billion gallons of sewage annually could be leaching into groundwater. This estimate of leakage is based on the unverified assumption of 5 percent leakage.

Because interstate pipelines are a major means of transporting materials, they are regulated by the Department of Transportation (DOT); and any leaks and spills must be reported to DOT (see ch. 3 and app. B.1). However, collection and distribution systems, gas stations, residential users, and even relatively large intrastate carriers are not required to report leaks and spills. Collection and distribution pipelines are not regulated other than during their initial installation to prevent the escape of combustible, explosive, or toxic chemicals; the potential for groundwater contamination is not a primary consideration.

About 4,100 non-waste liquid pipeline leaks and accidents were reported from 1968 through 1981 (DOT, 1981; the figure is not certain because information differs on pp. 21 and 39). Of that number, 2,813 occurred from 1971-81, with 3.4 million bbls of material lost. In 1981, 239 pipeline failures were reported, with 214,384 bbls lost; various products were involved in the leaks: crude oil was involved in 48.1 percent of the failures, gasoline in 19.3 percent, liquified petroleum gas (LPG) in 14.6 percent, natural gas liquid (LNG) in 5.0 percent, and fuel oil in 4.6 percent. The remaining materials involved were jet fuel, diesel fuel, anhydrous ammonia, kerosene, turbine fuel, oil and gas, and condensate.

19. Material Transport and Transfer Operations

Material transport and transfer operations refer to the movement of substances by vehicle (e.g., truck and railroad) along transportation corridors. Handling facilities such as airports and loading docks are also included.

Development of Estimates of Numbers and Amounts

Estimates of the number of spills vary. The National Academy of Sciences (NAS) estimated that approximately 16,000 spills occur annually, involving a variety of substances such as paint products, battery fluids, gasoline, corrosive compounds, flammable compounds, various acids, and anhydrous ammonia (NAS, 1983b). The Council on Environmental Quality (CEQ) (1982) reported on 10,072 known spills of oil or hazardous chemicals totaling 19.6 million gallons in 1981; however, these spills include leaks from storage pipelines and drains as well as from transportation facilities. DOT reported 9,063 incidents involving hazardous materials in 1981 and 6,540 in 1982 (as of Apr. 30, 1983; Jossi, 1983). Almost 81 percent of the 1982 incidents involved commercial carriers on highways, another 5 percent involved private carriers on highways, 13 percent involved railways, and the remainder involved other forms of transportation.

Very little information was available about the amount of hazardous materials lost in spills, other than the CEQ figure cited above; and no information was available regarding non-hazardous materials. NAS estimated that about one-half of the 4 billion tons of hazardous materials transported annually in the United States is transported on highways (NAS, 1983b). EPA (*Inside EPA*, 1983c) estimated that about 90 percent of all transportation of hazardous wastes is by truck. Further, EPA also estimated that when hazardous materials are transported by truck, approximately 0.35 percent of the hazardous materials (slightly more than 38 gallons) are lost during each shipment of 200 55-gallon drums. Assuming that the same 0.35 percent loss rate applies to the entire 4 billion tons shipped annually in the United States, no matter how transported, approximately 14 million tons of hazardous materials are spilled during material transport and transfer operations. This estimate is only a first approximation.

Potential for Groundwater Contamination

Transport and transfer of materials have the potential to contaminate groundwater contamination through spills and leaks. Spills are generally unintentional and can occur at random at transport facilities and along transportation corridors. Although an estimate can be developed for the amount of material spilled annually (see above), it is not possible to estimate the amount of spilled material that threatens groundwater.

Storage and transfer facilities for oil and hazardous chemicals must be designed and certified by a registered engineer if they pose a threat to surface water (University of Oklahoma, 1983). However, similar design requirements do not exist at the Federal level or in many States for groundwater (University of Oklahoma, 1983; see app. H.3). Design procedures that would take into account the potential for groundwater contamination relate to (API, 1976): drainage systems at loading and unloading areas, containment systems for possible spills, security measures, and tanker/tank design and interface.

20. Irrigation Practices

Water used for irrigation tends to percolate into the subsurface and move toward discharge points. As it does, it carries with it substances applied to and associated with the soil (e.g., fertilizers, pesticides, and sediment).

Development of Estimates of Numbers and Amounts

About 14 percent of cropland in the United States is irrigated; 58 million acres were irrigated in 1977 (USDA, 1981a), and 51 million acres were irrigated in 1978 (U.S. Department of Commerce, 1982). Irrigation is most common in the West, the Central and Southern Plains, Arkansas, and Florida (U.S. Department of Commerce, 1982). Approximately 169 million acre-feet of water were used for irrigation in 1980 (CEQ, 1982; the figure includes both surface water and groundwater). About 68 percent of the total groundwater use in 1980 was for irrigation (USGS, 1984).

Potential for Groundwater Contamination

Although salts, pesticides, and fertilizers may be present wherever crops are grown, irrigation return flows tend to concentrate these chemicals (University of Oklahoma, 1983) and can reduce agricultural productivity. Groundwater salinity (i.e., dissolved salts) can increase because of evaporation, transpiration, and subsequent leaching of saline soils. Irrigation practices have increased groundwater salinity in many parts of the West and Southwest (Sheridan, 1981).

Data are lacking about the proportion of irrigation water that is consumed by crops, percolates into the subsurface, and runs off the land. Salinity is difficult to reduce because the volume of irrigation water is difficult to alter and because much of the salt in water occurs naturally. However, various water conservation practices and the application of more efficient irrigation technology can decrease salinity significantly (USDA, 1981b; OTA, 1983b).

21. Pesticide Applications

Pesticides are chemicals used for control of insects, fungi, and other undesirable organisms and weeds. Agricultural operations (including but not limited to those on irrigated lands) account for most pesticide use (69-72 percent), government agencies and industrial/commercial organizations account for 21 percent, and home and garden uses account for the remainder (EPA, 1980a; Seiber, 1981).

Pesticide Production and Estimates of Use

Approximately 1.4-1.5 billion pounds of pesticides are produced in the United States each year (USDA, 1983a; EPA, 1977b; Forest Pest Management Institute, 1982). Production has doubled since the mid-1960s (EPA, 1980e) and is growing approximately 1.4 percent annually (Forest Pest Management Institute, 1982). Pesticides are composed of 1,200-1,400 active ingredients in approximately 2,500 intermediate products; these products in turn are formulated into some 50,000 registered end-use pesticide products (Roelofs, 1983; EPA, 1977b). Depending on the definition, there are approximately 30-80 major pesticide manufacturers, 100 smaller producers, 3,300 formulators, and 29,000 distributors in the United States (EPA, 1980a; USDA, 1983a).

Of the 1.43 billion pounds of end-use products manufactured in 1981, 839 million pounds were herbicides, 448 million pounds were insecticides, and 143 million pounds were fungicides. In 1982, it is estimated that 57.8 percent of the herbicides were amides and triazines and that 69.9 percent of the insecticides were organophosphates (Schaub, 1983).

Use of pesticides on cropland can be measured by the pounds of active ingredients applied and by the number of acre-treatments (i.e., the number of acres treated, including acres treated more than once). Approximately 552 million pounds of *active ingredients* were applied to major field crops in 1982 (USDA, 1983c)—451 million pounds of herbicides, 71 million pounds of insecticides, and 30 million pounds of fungicides, fumigants, dessicants, defoliants, growth regulators, and miticides. Pesticide applications may average as much as 2.6 pounds per acre (USDA, 1981a); in 1976, 2.2 pounds of insecticides and 2.0 pounds of herbicides were applied per acre (CEQ, 1982). However, new products have been developed which require as little as 0.1 pound of active ingredients per acre (Schaub, 1983); some new chemicals may require even less (Kearney, 1983).

Approximately 280 million acre-treatments are conducted annually (Schaub, 1983; USDA, 1978). The four major crops—corn, cotton, soybeans, and wheat—

account for 85 percent of all herbicide use and 70 percent of all insecticide use (Eichers, 1981). Forty-seven percent of all insecticides are applied to cotton (USDA, 1981a). About 85-90 percent of the corn, cotton, soybean, and rice acreage is treated with herbicides.

Airplane applications accounted for 65 percent of all pesticide applications on agricultural and forest lands in 1978 (USDA, 1978). These applications involved some 10,000 aircraft treating more than 180 million acres (Kearney, 1983).

Potential for Groundwater Contamination

Groundwater contamination from the use of pesticides in agricultural operations has been found in at least 18 States (Cohen, et al., 1984; Rothschild, et al., 1982; Spalding, et al., 1980); at least 12 different pesticides were involved (Cohen, et al., 1984). Contamination can occur from common use practices, spills, accidents, disposal of excess pesticides, disposal of wastewater from equipment and from rinsing empty containers, and other causes (Hall, 1983; *Chemical and Engineering News*, 1983). Contamination potential can generally be reduced through methods of use, storage, and disposal (*Chemical and Engineering News*, 1983).

However, airplane applications pose special problems. The disposal of wastewater from airplanes (either before or after landing) is often haphazard and may take place in ditches, lagoons, streams, and sewers or on the land (Seiber, 1981). It is estimated that the operation of one plane results in approximately 10,000 gallons of wastewater and 44 pounds of pesticides that must be disposed of each year (Seiber, 1981). Given the 10,000 aircraft involved, approximately 100 million gallons of wastewater and 440,000 pounds of pesticides must be disposed of annually.

Movement of pesticides through soil and into groundwater depends on a variety of pesticide-specific and site-specific factors including water solubility, vapor pressure, speciation, hydrolysis half-life, photolysis half-life, soil/water adsorption coefficient, depth to the water table, soil type, and rainfall (Cohen, et al., 1984; Severn, et al., 1983). Severn, et al. (1983) list quantitative conditions under which groundwater contamination can occur.

Many compounds do not move much with actual groundwater flow but adhere to and move with the soil particles themselves (e.g., many hydrocarbons; Hall, 1983). Other compounds are more soluble and move relatively rapidly (e.g., Temik or aldicarb; Hall, 1983); these compounds pose problems, especially in areas with high water tables (e.g., Florida). USDA is conducting at least 37 projects on the movement and fate of pesticides in the soil (Helling, 1983; also see ch. 3).

22. Fertilizer Applications

Farmers used 54.0 million tons of commercial fertilizers in 1980-81, 48.7 million tons in 1981-82, and 42.3 million tons in 1982-83 (USDA, 1983d). The areas covered are likely the same as those covered by pesticides and are spread throughout much of the country (University of Oklahoma, 1983; USDA, 1982a); the five States using the most fertilizer in both 1981-82 and 1982-83 were Illinois, Iowa, California, Indiana, and Texas (USDA, 1983d). Fertilizers used in 1981-82 contained 11.1 million tons of nitrogen (22.8 percent of the total 48.7 million tons), 4.8 million tons of phosphates (9.9 percent), and 5.6 million tons of potash (11.5 percent) (USDA, 1983d). The USDA has estimated that nutrient application rates range from 0.03-8.4 pounds per acre for nitrogen and from 0.01-0.08 pounds per acre for phosphorus (USDA, 1981b). In 1978, approximately 229 million acres were treated with commercial fertilizers and 17 million acres were treated with lime (U.S. Department of Commerce, 1982).

The potential for fertilizers to contaminate groundwater depends on the rate of application in relation to crop uptake (University of Oklahoma, 1983). This rate is often difficult to control because farmers generally apply enough fertilizer for the entire growing season prior to planting (Swanson, 1983).

23. Animal Feeding Operations

In the last two decades the number of animal feedlots with more than 1,000 animals has increased rapidly (Miller, 1980). In 1982, there were 1,935 cattle feedlots in the United States marketing approximately 16.8 million cattle; 969 of the feedlots, with a capacity of more than 2,000, marketed 15.3 million cattle (USDA, 1983b). The feedlots are located primarily in the Corn Belt and High Plains. Inventories of animals on farms and feedlots during 1978 showed a total of 106 million cattle and calves, 59 million hogs and pigs (USDA, 1982b), 12 million sheep and lambs, 2.2 million horses and ponies, more than 359 million chickens, and more than 140 million turkeys (U.S. Department of Commerce, 1982). The principal rearing region is the South for poultry, the West for sheep, and the Midwest for hogs.

Estimates of Manure Production

Cattle are estimated to produce 0.5 tons of manure during their 4-5 month stay in feedlots (Pye, et al., 1983). Thus in the larger cattle feedlots (i.e., with more than 1,000 animals), more than 8 million tons of manure are produced annually. The USDA has estimated that all livestock on feedlots and farms produce 175 million dry tons of manure annually, and 90 percent of it is returned to the land (USDA, 1981a).

Potential for Groundwater Contamination

Animal feeding operations can adversely affect groundwater if leachate enters the subsurface either directly from the feedlots or from waste piles and wastewater impoundments (see *Surface Impoundments*, above). The most important potential contaminant in manure is nitrogen, but bacteria, viruses, and phosphates are also of concern (University of Oklahoma, 1983).

The potential for groundwater contamination is greatest in areas with high densities of animals and a shallow water table. Thus even small farms have the potential to contaminate groundwater; large numbers of animals in a small area can stress the natural assimilative capacity of the soil (Pye, et al., 1983). Of the 718,000 farms with fewer than 300 animals, 25 percent are estimated to have the potential to degrade water quality (USDA, 1981b). Data are insufficient to estimate the volume of leachate and runoff that actually reaches the water table from large feedlots. In any case, because manure piles and feedlots often are near rural homes, domestic water supply wells are vulnerable.

24. De-Icing Salts Applications

Highway de-icing salts are applied to snow and ice-covered roads to improve driving conditions. The salts consist mostly of commercial rock and marine salt, with the addition of ferric ferrocyanide and sodium ferrocyanide to minimize caking of the salts when stored; other additives include chromate and phosphate, which reduce the corrosiveness of the salts (Bouwer, 1978). Use of highway de-icing salts is confined primarily to the snowbelt, especially the populous areas of the Northeast and Mideast, and is dependent on weather conditions.

Development of Estimates of Numbers and Amounts

During the winter of 1982-83, a minimum of 9.35 million tons of dry salts and abrasives and 1.78 million gallons of liquid salts were applied to highways (Salt Institute, 1983; data were for agencies using more than 10,000 tons of total materials annually). More than 12 million tons of salt were used in the 1978-79 winter (Pye, et al., 1983).

Highway salting rates generally range from 355-1,065 pounds per mile (100-300 kilograms (kg) per kilometer) per application. During the course of a winter season, roads typically receive 17.6 tons (16,000 kg) of salt per lane per mile, or approximately 88 tons (80,000 kg) per mile for a typical highway with four lanes and shoulders (Bouwer, 1978); this figure varies geographically and from year to year. During the 1982-83 winter, an average of 15.5 tons of dry salts and abrasives and 2.9 gallons of liquid salts were applied per lane per mile (based on Salt Institute, 1983).

Potential for Groundwater Contamination

Estimates of the total use of de-icing salts should be interpreted cautiously when attempting to assess their contribution to groundwater contamination. Although all salts used have the potential for reaching groundwater, the amounts likely to reach groundwater are unknown and depend on hydrogeological and other factors (University of Oklahoma, 1983).

Many cases of contamination caused by highway de-icing salts have been documented in snowbelt areas (Bouwer, 1978; Dalton, 1983; Lord, 1983). The sources are both the leachate from stockpiles of salt and the runoff from the roads. Major problems are primarily associated with the storage of salt (Lord, 1983); salt stockpiles are maintained year-round and are often entirely exposed.

Chloride levels in road runoff during snowmelt have been observed to range from 1,130-25,100 parts per million (Bouwer, 1978); drinking water is generally considered contaminated when chloride levels exceed 250 parts per million (NAS, 1980). Sodium ferrocyanide is soluble in water and, when exposed to sunlight, can generate cyanide in concentrations in excess of maximum drinking water limits (see app. C.3). Chromate additives can produce excessive concentrations of hexavalent chromium in meltwater (Bouwer, 1978).

Technology is now available to minimize leaching from salt stockpiles, but most research is being focused on what happens after application of de-icing salts (Lord, 1983). For example, the potential for groundwater contamination after application can be reduced by designing roads that require less de-icing and by collecting and disposing of the runoff, by developing substitute highway materials for maintaining safe driving conditions, and by developing alternatives to the de-icing salts now used.

25. Urban Runoff

Urbanization necessarily expands the areas that are impervious to rainfall and thus increases the amount and rate of surface runoff. The runoff, in turn, is channeled by extensive drainage networks and carries with it the contaminants associated with urban activities (e.g., automobile emissions, litter, deposited atmospheric pollutants, and sediments; University of Oklahoma, 1983). Any stormwater that infiltrates the surface can also carry these contaminants.

According to EPA (1983c), over 21.2 million urban acres contributed stormwater runoff in 1970, and this figure is projected to increase to 32.6 million acres by the year 2000. Data are insufficient to determine the extent to which urban runoff and infiltrating stormwater contribute to groundwater contamination.

Potential for Groundwater Contamination

Urban runoff is a primary cause of degraded surface water quality in heavily populated areas. After flowing into existing water bodies, contaminants originally carried in runoff may accumulate in solution or in sediments (Owe, et al., 1982). The potential for groundwater contamination from urban runoff will depend on where the runoff is discharged, its proximity to aquifers, and various hydrogeologic factors.

A major source of contaminants is automobile emissions, which may contribute contaminants to surface runoff in some areas. The contaminants of most concern are suspended solids and toxic substances, especially heavy metals and hydrocarbons. Runoff can also contain bacteria, nutrients, and other oxygen-demanding loads, and petroleum residues (USDA, 1981a; Owe, et al., 1982). Contaminant levels in urban runoff are often higher than established ambient levels for receiving waters (Owe, et al., 1982).

26. Percolation of Atmospheric Pollutants

Many potential contaminants of groundwater are carried in the atmosphere and eventually reach the land surface through either dry deposition between storms or transport in water and snow during storms (Owe, et al., 1982). A number of sources of atmospheric pollutants are known, among them automobile emissions and various industrial processes. The major contaminants are sulfur and nitrogen compounds, asbestos, and heavy metals (Owe, et al., 1982). Their ultimate distribution depends on their size when they are released and on weather patterns while they are moving in the atmosphere.

Percolation of atmospheric pollutants into groundwater is greatest in areas of high air pollution. One of the better-studied cases involves acid rain. Although widely distributed, acid rain occurs predominantly around the Great Lakes, the Northeast, and south-central Canada (OTA, 1984).

27. Mining and Mine Drainage

Minerals are extracted by either underground mining or surface mining. Underground mining is used to extract deep, relatively high-grade ore from structurally stable rock. The methods used (e.g., room-and-pillar, block caving, and stoping; NAS, 1979) depend on topography, geology, and characteristics of the ore (e.g., size, shape, depth, and ore grade). In surface mining, pits are created when the overburden and topsoil are removed to expose large, shallow deposits (generally covered with less than 300 feet of loose soil; NRC, 1983); operations include quarrying, open-pit, opencut, opencast, stripping, placering, and dredging (NAS, 1979). Deep underground mines, especially for coal, are located primarily in the Appalachian region; and surface mines are primarily in the West and Midwest.

Development of Estimates of Numbers and Amounts

More than 15,000 mines were in operation in 1976 (NAS, 1979). Wirries, et al. (1983) estimate that there are also 67,000 inactive or abandoned mines in the conterminous United States, 49,000 of them in the Midwest and Appalachia. The total land area that has been disturbed has been estimated at 4 million acres; the rate of disturbance may have been as high as 5,000 acres per week in the early 1970s (NAS, 1979). Approximately 383,000 acres have been abandoned.

Miller (1980) estimated that 3.6 million tons of acid were generated annually from the 200,000 acres used for the disposal of coal mining wastes (27,000 of those acres had been reclaimed). Depending on how many of the approximately 383,000 abandoned acres are also used for waste disposal, the amount of acid generated annually could be as high as 10 million tons (the additional acreage triples the total acreage and presumably the subsequent estimate). Miller (1980) also estimated that 10 percent of the acid generated enters groundwater; thus 0.36-1.0 million tons of acid could enter groundwater each year.

Potential for Groundwater Contamination

Excavation and *operation* of both surface and underground mines can disrupt the natural positioning of aquifers and hence groundwater flow. As a consequence, water can percolate through the fractured overburden and mix with mine wastes and other materials that were previously separated (NRC, 1983; EPA, 1981a). The problem can be minimized by dewatering (e.g., pumping water to the surface, possibly at rates of up to 200-3,000 gallons per minute; NRC, 1983).

The primary problem concerning groundwater relates to the disposal of spent mill tailings, especially in underground mining. Underground mining introduces oxygen and water, which can result in the oxidation of pyrite and the subsequent formation of acid mine drainage—an acidic mixture of iron salts, other salts, and sulfuric acid (Thomson, et al., 1983). Acid mine drainage is a major problem in the East; in the West, groundwater seldom becomes acidic, usually because carbonates in the overburden help neutralize any acid produced. However, sulfate concentrations are often very high in Western surface mined lands. Arsenic, molybdenum, vanadium, and other minerals also can become soluble in the oxidizing conditions of mining in general and can enter groundwater.

Wirries, et al. (1983) studied inactive deep underground coal mines in Appalachia and the Midwest. Drainage quality was highly variable, with most sites exceeding Federal effluent guidelines. Trace metals (e.g., cadmium, mercury, zinc, and nickel) were present in low concentrations. Calcareous material in the overburden helped buffer acid drainage. The amount and rate of acid formation and the chemical quality of the drainage tend to be functions of the amount and type of pyrite present, characteristics of the overburden, and the amounts of air and water available for chemical reactions (EPA, 1981a).

28. Production Wells

A variety of wells are included as production wells—oil, geothermal and heat recovery, and water supply wells. Oil wells are clustered in the Southwest, Alaska, Louisiana, Wyoming, and the Midwest. Geothermal activities are primarily in the West and in the heavily populated northern States where the use of earth-coupled heat pumps is increasing (University of Oklahoma, 1983). No comprehensive information on the location of water supply wells was collected as part of this study, but they are likely to be most numerous in areas with high groundwater withdrawals (the Southwest, the Central Plains, Idaho, and Florida; see Solley, et al., 1983).

Approximately 548,000 oil wells produced an estimated 3.1 billion bbls of crude oil in 1980 (U.S. Department of Commerce, 1981); the brine associated with these wells is discussed in *Injection Wells*, above. Abandoned production wells may number around 1.2 million (Kaplan, et al., 1983).

More than 376,000 irrigation wells are used to supply water for approximately 126,000 farms in the United States (*The Groundwater Newsletter*, 1983b).

All production wells share a similar potential to contaminate groundwater. It is related to installation and operation methods (e.g., for oil wells, the use of treatment chemicals, drilling fluids, and other chemicals), incorrectly plugged or abandoned wells, cross-contamination, and overdraft. Corrosion of screens and casings in unrepaired or abandoned wells can result in the wells becoming conduits for the vertical migration of contaminants (Gass, et al., 1977; see *Injection Wells*, above, for discussion of groundwater contamination problems associated with wells).

29. Other Wells

Other wells include those used in various monitoring and exploration activities. No systematic information is available regarding numbers and locations of these wells.

30. Construction Excavation

Excavation at construction sites has many purposes including: clearing, pest control, rough grading, facility construction, and the restoration of staging and stockpile areas upon completion of a job (University of Oklahoma, 1983). Construction excavation is intense in areas experiencing growth, but it is usually temporary.

Almost no data are available on the amount of materials that is excavated annually. It has been estimated that 45 million tons of junked auto, construction, and demolition wastes are generated annually (EPA, 1981b) but how much of these wastes results from construction excavation is not known.

Excavation at construction sites can produce potential groundwater contaminants in a variety of ways. Clearing and grubbing and pest control practices can produce contaminants from the use of pesticides and the decay of cleared vegetation. Heavy construction equipment used for rough grading can spill diesel fuel, oil, and lubricants. Some construction activities can include dust control in which oil, calcium chloride, and water are used. The concrete used in construction is a source of contaminants from washing, spills, and wastes (University of Oklahoma, 1983).

31. Groundwater—Surface Water Interactions

When groundwater aquifers are hydrologically connected with surface water, the aquifer can be partially recharged by infiltration of the surface water.[4] If the surface water is contaminated, or if it reacts chemically with the subsurface materials as it infiltrates downward, degradation of groundwater quality can follow (Miller, 1980).

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[4] Alternatively, groundwater may replenish surface water, e.g., it may provide the baseflow for streams and rivers. In this case, contaminants in groundwater could be transferred to surface water.

32 Natural Leaching

Natural leaching occurs on a local scale in aquifers, or in portions of aquifers, whose geologic materials can be dissolved into solution. No systematic information is available about the significance of natural leaching to groundwater contamination.

33. Salt-Water Intrusion/ Brackish Water Upconing

Approximately 21 billion gallons of groundwater per day—26 percent of all groundwater withdrawn (USDA, 1981a)—are withdrawn in excess of recharge capabilities (i.e., overdrafting, overpumping, or overmining). Withdrawals significantly in excess of natural recharge are located predominantly in coastal areas (e.g., California, Texas, Louisiana, Florida, and New York), the Southwest, and the Central Plains (USDA, 1981b).

Overdrafting can disrupt the natural hydrologic processes associated with groundwater; and subsequent impacts on aquifers and groundwater quality include: salt-water intrusion in coastal areas, brine-water intrusion (or brackish water upconing) in inland areas, and intensified natural leaching. Land subsidence may also result; it disrupts the natural positioning of aquifers and has additional surface impacts (e.g., subsidence). Salt-water or brine-water intrusion is probably the major problem associated with overdraft but it occurs only in areas where freshwater aquifers are underlain by salt-water or brine. At some coastal areas, injection of freshwater into aquifers is used to prevent salt-water intrusion (University of Oklahoma, 1983).

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Appendix B

Federal Institutional Framework To Protect Groundwater

B.1 DESCRIPTION OF SOURCES ADDRESSED BY FEDERAL PROGRAMS (p. 296)

B.1 DESCRIPTION OF SOURCES ADDRESSED BY FEDERAL PROGRAMS[a]

Source	Statute and Section	Description of Sources[b]	Provisions of Federal Programs to Protect Groundwater[b]		
			Detection	Correction	Prevention
CATEGORY I:					
Subsurface Percolation	SDWA - Part C	Cesspools (or similar devices) serving 20 or more persons (included in Class V well category).[c]			
	CWA - Section 201	On-site septic systems serving one or more residences or small commercial establishments.			
Injection Wells	SDWA - Part C	Wells are divided into five categories: 1) Class I - Wells used to dispose of hazardous, radioactive and other wastes below aquifers used for drinking water purposes. 2) Class II - Wells used in association with oil and gas production (e.g., enhanced recovery, or for storage of liquid hydrocarbons). 3) Class III - Wells used for the extraction of minerals (e.g., in-situ and solution mining). 4) Class IV - Wells used to dispose of hazardous or radioactive wastes into or above drinking water sources. 5) Class V[c] - Other injection wells not specified above (e.g., artificial recharge wells).	X		X
	CERCLA	Injection wells which release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	X	X	
Land Application	CWA - Section 201	Land treatment processes for wastewater from sewage treatment plants.	X	X	X
	CWA - Section 405	Land treatment of sewage sludge.	X	X[d]	X
	CWA - Section 404	Land application of dredged material.			X
	RCRA - Subtitle C	Land treatment of hazardous wastes (as defined by RCRA).[e]	X	X	X
	CERCLA	Land applications that release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	X	X	

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Source	Statute and Section	Description of Sources	Provisions of Federal Programs to Protect Groundwater		
			Detection	Correction	Prevention
CATEGORY II:					
Landfills	RCRA - Subtitle C	Landfills used for the disposal of hazardous wastes (as defined by RCRA).[e]	X	X	X
	TSCA - Section 6	Landfills used for the disposal of PCBs (at concentrations of 50 ppm and above).	X		X
	RCRA - Subtitle D	Sanitary landfills are facilities that pose no reasonable probability of adverse effects on health or the environment from disposal of solid wastes (as defined by RCRA).			X
	CERCLA	Landfills that release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	X	X	
Open Dumps	RCRA - Subtitle D	Open dumps are defined as landfills that do not meet the specified criteria for sanitary landfills.			X
	CERCLA	Open dumps that release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	X	X	
Residential (local) Disposal	FIFRA - Section 19	Burial of small quantities of pesticide containers in open fields.			X
Surface Impoundments	RCRA - Subtitle C	Surface impoundments used for the treatment, storage, or disposal of hazardous wastes (as defined by RCRA).[e]	X	X	X
	CERCLA	Surface impoundments that release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	X	X	
	SMCRA	Temporary and permanent impoundments associated with surface and underground coal mining operations.	X		X
	FLPMA and Associated Mining Laws	Impoundments associated with mining operations for leasable minerals (e.g., phosphate, sand, and gravel), locatable minerals (e.g., gold, silver, and copper) and geothermal steam production. Applies only to Federal lands.			X

Source	Statute and Section	Description of Sources	Provisions of Federal Programs to Protect Groundwater		
			Detection	Correction	Prevention
CATEGORY II (Cont'd.)					
Waste Tailings	UMTRCA	Waste tailings disposal areas (active) from uranium processing activities.	X	X	X
	UMTRCA	Waste tailing disposal areas (inactive) from uranium processing activities.	X	X	
	FLPMA and Associated Mining Laws	Waste tailings associated with mining operation for leasable and locatable minerals. Applies only to Federal lands.			X
Waste Piles	RCRA - Subtitle C	Waste piles used for the storage or treatment of hazardous wastes (as defined by RCRA).[e]	X	X	X
	CERCLA	Waste piles that release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	X	X	
	SMCRA	Coal mine waste piles (e.g., earth materials separated from the coal) associated with surface and underground mining operations.	X		X
	FLPMA	Mine waste piles associated with mineral mining operations. Applies only to Federal lands.			X
Materials Stockpiles	FIFRA -- Section 19	Storage of pesticide packages and containers.			X
Graveyards	---	---			
Animal Burial	---	---			
Aboveground and Underground Storage Tanks	RCRA - Subtitle C	Tanks used for the treatment or storage of hazardous wastes (as defined by RCRA).[e,f]			X
	CERCLA	Tanks that release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	X	X	
	TSCA - Section 6	Tanks containing PCBs (at concentrations of 50 ppm and above).			X

Source	Statute and Section	Description of Sources	Provisions of Federal Programs to Protect Groundwater		
			Detection	Correction	Prevention
Aboveground and Underground Storage Tanks (Cont'd.)	CWA - Section 311	Facilities with aboveground tank capacities equal to or greater than 1,320 gallons of oil (or single tanks with capacities greater than 660 gallons) or facilities with underground tank capacities equal to or greater than 42,000 gallons of oil.			X
Containers	RCRA - Subtitle C	Containers used to store hazardous wastes (as defined by RCRA).			X
	TSCA - Section 6	Containers used to store PCBs (at concentrations of 50 ppm and above).			X
	CERCLA	Containers that release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	X	X	
	FIFRA - Section 19	Pesticide containers (see Materials Stockpiles, above).			X
Open Burning and Detonation Sites	RCRA - Subtitle C	Open burning and detonation of waste explosives (open burning of hazardous wastes is prohibited).[g]			X
	FIFRA - Section 19	Open burning of small quantities of combustible pesticide containers.			X
	CERCLA	Open burning and detonation sites that release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	X	X	
Radioactive Disposal Sites	AEA	Disposal sites for low-level radioactive wastes.	X	X	X
	AEA	Geologic repositories for high-level radioactive wastes.	X		X
	AEA	Facilities used to store and process nuclear materials.	X	X	
	UMTRCA	(See Waste Tailings, above.)	X	X	X

Source	Statute and Section	Description of Sources	Provisions of Federal Programs to Protect Groundwater		
			Detection	Correction	Prevention
CATEGORY III:					
Pipelines	HLPSA	Pipelines used to transport hazardous liquids (applies to petroleum, petroleum products, and anhydrous ammonia) in interstate and foreign commerce.			X
	CERCLA	Pipelines that release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	X	X	
Materials Transport and Transfer Operations	HMTA	Transport of hazardous materials and hazardous wastes (as defined by HMTA) by rail car, aircraft, vessel, and motor vehicles used in interstate and foreign commerce, and by motor vehicles used to transport hazardous wastes in intrastate commerce.			X
	CERCLA	Transport-related releases of any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	X	X	
CATEGORY IV:					
Irrigation Practices	CWA - Section 208	Return flows from irrigated agriculture.			X
Pesticide Applications	CWA - Section 208	Agriculturally related non-point sources of pollution.			X
	FIFRA - Section 3	Application of certain pesticides which may cause unreasonable adverse effects on the environment.			X
Fertilizer Applications	CWA - Section 208	Agriculturally related non-point sources of pollution.			X
Animal Feeding Operations	CWA - Section 208	Manure disposal areas and land area used for livestock.			X
De-icing Salts Applications	---	---			
Urban Runoff	CWA - Section 208	Urban stormwater runoff systems.			X
Percolation of Atmospheric Pollutants	--	--			

Source	Statute and Section	Description of Sources	Provisions of Federal Programs to Protect Groundwater		
			Detection	Correction	Prevention
CATEGORY IV (Cont'd.):					
Mining and Mine Drainage	FLPMA and Associated Mining Laws	Surface and underground mining operations for leasable and locatable minerals. Applies only to Federal lands.			X
	SMCRA	Surface and underground coal mining operations.	X		X
	CWA - Section 208	Mine-related sources of pollution including runoff from new, active, and abandoned surface and underground mines.			X
CATEGORY V:					
Production Wells[h]	FLPMA (and Geothermal Steam Act)	Wells used for the development of geothermal steam. Applies only to Federal lands.	X		X
Other Wells (Non-waste)	FLPMA	Exploration wells used in mining operations for leasable minerals. Applies only to Federal lands.			X
Construction Excavation	CWA - Section 208	Construction activity related to sources of pollution.			X
CATEGORY VI:					
Groundwater - Surface Water Interactions	CWA - Section 208	Intermixing of surface water and groundwater.			
Natural Leaching	Reclamation Act	Natural salt or other deposits affecting underground water supplies.	X	X	
Salt-water Intrusion	CWA - Section 208	Salt-water intrusion into surface water resulting from reduction of freshwater flow from any cause including groundwater extraction.			X
	CZMA	Salt-water intrusion.			

[a] Additional information about the applicability of CERCLA to various sources is presented in the text. See footnote 11 in ch. 3.

[b] The descriptions listed are based on Federal regulations or other documents issued by Federal agencies with respect to the implementation of statutory requirements.

[c] Regulations for Class V wells have not been promulgated.

[d] Corrective action provisions for land treatment of sewage sludge are included in Section 201 of the Clean Water Act.

[e] Certain design and operation requirements do not apply to facilities (or portions of facilities) that received waste prior to the effective date of the regulations (Jan. 26, 1983). The definition of hazardous waste is discussed in footnote 12 in ch. 3.

As this report went to press, the Report of the Conference Committee, House Report No. 98-1133, had been adopted on a bill to reauthorize and amend RCRA and awaits enactment from the White House. Provisions of the bill (H.R. 2867) are not included in the OTA analysis of Federal laws and programs. Provisions of the bill are included for, among others, liquids in landfills, land disposal, small-quantity generators, underground storage tanks, waste facility standards, and surface impoundments. Some provisions directly address groundwater, For example, EPA must issue regulations for detecting leaks from underground tanks used to store hazardous substances and petroleum products; all new or expanded land disposal facilities for hazardous wastes must have groundwater monitoring; underground injection of hazardous wastes into or above any formation that contains, within one-quarter mile of the well, an underground source of drinking water is prohibited (variances are allowed); and a National Groundwater Commission is established. The reader is referred to: Congressional Quarterly, "RCRA Rewrite Strengthens Hazardous Waste Protections," Oct. 6, 1984; and M. E. Reisch, "RCRA Reauthorization: A Section-by-Section Comparison of H.R. 2867, As Passed By the House, and As Passed, Amended (S. 757), by the Senate," Congressional Research Service, revised Aug. 6, 1984.

[f] Regulations for underground tanks containing hazardous wastes have not been promulgated.

[g] Regulations for open burning and detonation sites have not been promulgated.

[h] Injection wells used for the production of minerals are included in Category I (Injection Wells) above.

Source: Office of Technology Assessment.

Appendix C

State Institutional Framework To Protect Groundwater

C.1 AGENCIES THAT RESPONDED TO THE OTA STATE SURVEY (p. 304)
C.2 OTA STATE SURVEY (p. 307)
C.3 SUBSTANCES WITH STATE STANDARDS OR FEDERAL STANDARDS OR GUIDELINES FOR WATER QUALITY THAT MAY BE APPLIED TO GROUNDWATER (p. 333)
C.4 OTA STATE SURVEY RESPONSES: EXAMPLES OF STRENGTHS, PROBLEMS, AND DESIRED FEDERAL ASSISTANCE FOR EACH STATE (p. 349)
C.5 OTA STATE SURVEY RESPONSES: SELECTED STATE ISSUES (p. 387)

C.1 AGENCIES THAT RESPONDED TO THE OTA STATE SURVEY

Alabama Department of Environmental Management

Alaska Department of Environmental Conservation

Arizona Department of Health Services
Arizona Department of Water Resources

Arkansas Department of Pollution Control and Ecology

California State Water Resources Control Board
California Department of Health Services
California Department of Water Resources

Colorado Department of Health

Connecticut Department of Environmental Protection

Delaware Department of Natural Resources and Environmental Control

Florida Department of Environmental Regulation

Georgia Department of Natural Resources -- Environmental Protection Division

Hawaii Department of Health
Hawaii Department of Land and Natural Resources
Hawaii Department of Agriculture

Idaho Department of Health and Welfare -- Division of Environment
Idaho Department of Water Resources

Illinois Environmental Protection Agency
Illinois State Water Survey

Indiana State Board of Health -- Division of Water Pollution Control

Iowa Department of Water, Air, and Waste Management

Kansas Bureau of Oil Field and Environmental Geology

Kentucky Natural Resources and Environmental Protection Cabinet
    Department of Environmental Protection
    Department of Natural Resources
    Department for Surface Mining Reclamation and Enforcement
Kentucky Commerce Cabinet
    Department of Agriculture
Kentucky Geological Survey
Kentucky Human Resources Cabinet
    Department of Health Services
Kentucky Public Protection and Regulation Cabinet
    Department of Mines and Minerals

Louisiana Department of Natural Resources
Louisiana Department of Health and Human Services
Louisiana Department of Transportation and Development -- Division of Water Resources
Capital Area Groundwater Commissioner

Maine Department of Environmental Protection

Maryland Department of Health and Mental Hygiene

Massachusetts Department of Environmental Quality and Engineering

Michigan Department of Natural Resources

Minnesota Pollution Control Agency

Mississippi Department of Natural Resources
Mississippi State Board of Health
Mississippi Oil and Gas Board

Missouri Department of Natural Resources

Montana Department of Health and Environmental Sciences

Nebraska Department of Environmental Control
Nebraska Department of Health

Nevada Department of Conservation and Natural Resources

New Hampshire Water Supply and Pollution Control Commission

New Jersey Department of Environmental Protection

New Mexico Health and Environment Department
New Mexico Office of the State Engineer
New Mexico Department of Agriculture

New York Department of Environmental Conservation

North Carolina Department of Natural and Community Resources

North Dakota State Health Department

Ohio Environmental Protection Agency

Oklahoma Department of Pollution Control
Oklahoma Department of Mines
Oklahoma Water Resources Board
Oklahoma State Department of Health
Oklahoma Corporation Commission

Oregon Department of Environmental Quality

Pennsylvania Department of Environmental Resources

Rhode Island Department of Environmental Management

South Carolina Department of Health and Environmental Control
South Carolina Water Resources Commission

South Dakota Division of Water and Natural Resources Management

Tennessee Department of Health and Environment

Texas Department of Water Resources

Utah Department of Environmental Health
Utah Department of Natural Resources and Energy

Vermont Department of Water Resources and Environmental Engineering

Virginia State Water Control Board
Virginia State Department of Health

Washington Department of Ecology

West Virginia Department of Natural Resources

Wisconsin Department of Natural Resources

Wyoming Executive Department

Source: Office of Technology Assessment.

C.2 OTA STATE SURVEY

Please return the following questionnaire on:

STATE ACTIVITIES ON GROUNDWATER CONTAMINATION

To the:

Office of Technology Assessment
Groundwater Contamination Project
U.S. Congress
Washington, D.C. 20510

by: August 1, 1983

include:

- State name:____________________________________
- Name and title of principal contact:____________________________________
- Telephone number of contact:____________________

Questions should be directed to: Joan Harn
202-26-2155

STATE ACTIVITIES ON GROUNDWATER CONTAMINATION

Objective: To learn about state efforts to detect, correct and prevent groundwater contamination and to improve state capabilities to deal with this problem.

To learn about state priorities among these four categories.

To learn of the impact of federal programs on state efforts to deal with groundwater contamination.

Introduction: Actions to deal with groundwater contamination include: detection, correction, prevention, and improving capabilities to deal with problems. A major policy issue for the U.S. Congress is to determine how to allocate among these 4 activities, scarce resources that the federal government may expend on groundwater contamination. To provide information to Congress that will help them to allocate federal resources, OTA would like information from the states on their technical knowledge and experience with these four activities and the relative importance the states give to each activity. Federal efforts to address groundwater contamination to date have taken a variety of forms: research, data collection, technical assistance, grants and cost-sharing programs, and regulations. To evaluate options for future federal involvement related to groundwater contamination, information from the states on the value of these past federal efforts is also essential.

Instructions: This questionnaire on state activities related to groundwater contamination is divided into eight sections: Sources, Detection, Corrective Actions, Prevention, Improving Capabilities, State Policies, Federal-State Relations and Impacts. To the extent possible please answer each of the questions in the space provided. Attach additional sheets, as needed. If you have trouble answering a particular question, please note why you are having difficulty and move on to the next question. A single coordinated response from each state is preferred, however, if this is not possible, please give all appropriate agencies an opportunity to respond directly to OTA. The questionnaire should be returned to OTA no later than AUGUST 1, 1983. Any questions should be directed to Joan Harn (202) 226-2155.

A. SOURCES OF GROUNDWATER CONTAMINATION

1. For each of the sources of groundwater contamination listed below, note whether the state has a program to detect (D), correct (C), prevent (P) and/or learn more about (L) groundwater contamination. Note if the state has no programs (N) for a particular source.

    a. Landfills
        i. sanitary
        ii. hazardous waste

    b. Open dumps

    c. Waste piles

    d. Surface impoundments

    e. Subsurface percolation systems (e.g., septic tanks, cesspools)

    f. Injection wells

    g. Disposal of waste treatment by-product (e.g., sludge)

    h. Disposal of waste waters (e.g., spray irrigation)

    i. Agriculture
        i. Irrigation return flow
        ii. Pesticides, herbicides
        iii. Feedlots
        iv. Fertilizers
        v. Runoff

    j. Salt-water intrusion brackish water upcoming

    k. Spills, accidents

    l. Leaks from storage, pipelines, etc.

    m. Transportation (e.g., airports, loading docks)

    n. Drainage from active/abandoned mines

    o. Infiltrating stormwater, urban runoff

    p. Percolation of atmospheric contaminants

    q. Aquifer disruption due to construction/excavation

    r. De-icing salts

    s. Abandoned wells

    t. Other (specify)

2. For each of the sources that the state does not have any programs, as noted in #1, explain why the source is/is not considered to be a problem. Possible reasons for a source not being considered to be a problem include: source does not occur in the state, status of the source is unknown, the source is very uncommon, no groundwater contamination problems have been detected from the source, etc. If the sources without programs are considered to be problems, or there is insufficient information to determine whether or not there is a problem, explain why the state does not have any programs.

3. Describe any strengths or weaknesses in state programs to deal with different sources of goundwater contamination.

4. Name and phone number of contacts to discuss sources of groundwater contamination:

B. DETECTION

5. What is the state doing to detect groundwater contamination incidents? Check the categories that apply to your state.

   - o Inventories of potential sources of contamination (note sources being inventoried)
   - o Monitoring program for quality assurance at point of use (note water uses being monitored)
   - o Systematic monitoring of potential sources (note sources being monitored)
   - o General ambient quality monitoring
   - o Routine comparison of monitoring data with quality standards
   - o Responding to complaints of suspected contamination
   - o No activity
   - o Other (specify)

6. What priorities does the state have in detecting contamination? Check the categories that apply to your state, and if possible, rank their importance (1 = highest priority)

o drinking water supplies

public - serving more than 75,000 persons
serving 10,000 - 75,000 persons
serving 25-10,000 persons
serving less than 25 persons
other (specify)

private

o other water supplies

industrial (self-supplied) - process water
- cooling water
- other (specify)

agricultural - livestock watering
- irrigation
- other

o particular sources of contamination (specify)

o particular types of contaminants (specify)

o particular types of contaminants (specify)

o no priorities

o other (specify)

7. Note which of the following techniques for the hydrogeologic investigation of groundwater flow and contaminant behavior are used by the state: Routinely (R), in Special Situations (S), Never (N). Also note which techniques are preferred (P).

A. Surface Geological
    A1. aerial photo
    A2. satellite
    A3. existing studies
    A4. mapping (soils, geology, topography)
    A5. other (specify)
    A6.

B. Subsurface Geological
    B1. test wells
    B2. stratigraphy
    B3. other (specify)
    B4.

C. Surface Hydrology
    C1. watershed analysis
    C2. climate
    C3. other (specify)
    C4.

D. Subsurface Hydrology
    D1. tracer tests
    D2. aquifer tests
    D3. modeling -- groundwater flow
    D4. modeling -- contaminant transport
    D5. other (specify)
    D6.

E. Surface Geophysical
    E1. surface potential
    E2. electrical resistivity
    E3. electromagnetic (surface penetrating radar)
    E4. sniffers
    E5. temperature
    E6. other (specify)
    E7.

F. Subsurface Geophysical
    F1. borehole geophysics
    F2. other (specify)
    F3.

8. Why does the state prefer to use particular techniques for hydrogeologic analysis?

9. Describe any technical, legal, and institutional problems the state has in using particular hydrogeologic techniques (e.g., cost, data requirements, technical expertise, safety, manpower, accuracy, uncertainty of possible interpretations, manpower, accuracy, uncertainty of possible interpretations, access to site, interference with water rights, etc.).

10. Name, title, and phone number of contacts to discuss advantages, disadvantages and problems of techniques for hydrogeologic analysis.

C. CORRECTIVE ACTIONS

11. What is the state doing to correct incidents of groundwater contamination? Check the categories that apply to your state and note the relative frequency of use (High, Moderate, Low, Never).

A. Containment

A1. slurry wall (conventional, continuous trencher, vibrating beam)
A2. grout curtain
A3. sheet piling
A4. surface sealing
A5. diversion ditches
A6. liners
A7. gas migration control
A8. mathematical modeling-groundwater flow
A9. mathematical modeling-containment transport
A10. artificial recharge
A11. natural containment
A12. other (specify)
A13.

B. In-situ Rehabilitation

B1. plume management (pressure troughs, pressure ridges)
B2. groundwater pumping/water table adjustment
B3. chemical immobilization
B4. bioreclamation
B5. mathematical modeling - groundwater flow
B6. mathematical modeling-contaminant transport
B7. other (specify)
B8.

C. Withdrawal/treatment

C1. withdrawal techniques

C1.i. pumping
C1.ii. suction
C1.iii. gravity
C1.iv. excavation
C1.v. other (specify)
C1.vi.

C2. treatment

C2.i. skimming
C2.ii. filtration
C2.iii. incineration
C2.iv. adsorption (GAC)
C2.v. airstripping
C2.vi. ion exchange
C2.vii. ultrafiltration
C2.viii. reverse osmosis
C2.ix. other (specify)

C. CORRECTIVE ACTIONS (Cont.)

D. Management Options

D1. terminate/limit aquifer use
D2. develop alternative water supply sources
D3. purchase alternative water supply
D4. treat at point of end-use (e.g., faucet filtering devices)
D5. restore via natural processes (not included under A, B, or C above)
D6. monitoring
D7. health advisories
D8. other (specify)
D9.
D10.

12. Discuss any technical, legal and institutional problems the state has had in the use of any of these techniques (e.g., well closings resulting in more rapid movement or changed direction of contaminant transport, difficulty with obtaining water rights, etc.).

13. Which techniques for corrective action are preferred? Why?

14. Name, title, and phone number of contacts for discussing advantages, disadvantages, and problems associated with these techniques for correcting groundwater contamination.

15. How does state decide to address contamination at one site as opposed to another? Check the categories that apply to your state, if possible rank their importance.

    o formal criteria (specify)

    o order in which contamination is detected

    o public pressure

    o sites where a source and responsible party can be identified

    o sites qualified for special funding (e.g., Superfund)

    o severity of problem (specify how determined)

    o other (specify)

D. PREVENTION

16. What is the state doing to prevent groundwater contamination from occurring? Check categories that apply to your state. Note whether the category has been implemented (I) or is in the process of being developed (D). If program is in the process of being developed, note whether new legislation (N) is required.

- o permits for discharges to groundwater based on technology requirements
- o permits for discharges to groundwater based on performance standards
- o voluntary best management practices
- o required best management practices
- o facility siting requirements
- o public education
- o classification
- o groundwater quality standards other than drinking water standards
- o well construction standards
- o well closing standards
- o non-degradation policy
- o policy to protect public health
- o policy to balance resource protection with costs of control
- o no action
- o other (specify)

17. What priorities does the state have for prevention? Check categories that apply to your state, if possible rank their relative importance.

    o protecting certain existing drinking water supplies (specify)

    o protecting certain aquifers (specify e.g., recharge areas, discharge areas, potential future water supplies)

    o eliminating potential for groundwater contamination from particular sources (specify)

    o no priorities

    o other (specify)

18. Name, title, and phone number of contacts to discuss prevention activities:

E. IMPROVING CAPABILITIES

19. What is the state doing to improve its capabilities to deal with groundwater contamination?

    - Special studies (specify)
    - Staff development and training
    - Facility development (specify, e.g., laboratory certification)
    - Public education
    - Agency reorganization
    - Coordination programs (specify)
    - Other (specify)

20. Name, title, and phone number of contacts to discuss improving state capabilities:

F. STATE POLICIES

21. Check the below listed activities for which the state has formal policies, written guidelines or procedures. Please send a copy, or briefly describe these policies, guidelines or procedures.

- o Standard protocols for collecting groundwater quality samples
- o Standard protocols for analyzing groundwater quality samples
- o Groundwater monitoring for drinking water supplies (if different than federal Safe Drinking Water Act requirements)
- o Groundwater monitoring at waste sites (if different than federal RCRA requirements)
- o Responding to complaints about possible groundwater contamination
- o Determining what groundwater parameters to measure at a particular locaton
- o Response when groundwater quality standards are violated
- o Response when there is no quality standard for a contaminant that is found in groundwater
- o Setting priorities for correcting groundwater contamination
- o Establishing the standard to which groundwater contamination will be cleaned up
- o Confidentiality of certain groundwater information that is collected by the state
- o Implementing policies for groundwater protection (e.g., classification, non-degradation, discharges to groundwater, etc.)

22. In the absence of formal policies, written guidelines or procedures for the items listed in #21, how does the state determine what to do?

23. For which substances has the state established standards for groundwater that are more stringent than federal primary or secondary drinking water standards? What is the technical basis for these more stringent standards (e.g., SNARL's, minimum detection levels)? Why did the state decide to develop these more stringent standards?

24. Name, title, and phone number of contacts to discuss implementation of formal policies on groundwater contamination:

25. Approximately how much money (i.e., order of magnitude) is the state devoting to each of the following activities related to groundwater contamination:

Detection

Correction

Prevention

Improving Capabilities

If you are unable to provide an estimate of funds expended on groundwater contamination, please explain why.

26. What is the relative importance the state gives to each of the 4 categories listed below? (1 = highest) On what basis do you make this ranking?

Detection

Correction

Prevention

Improve capabilities

27. What do you suspect will be the relative importance of each of the categories listed below in ten years? (1 = highest) On what basis do you make this ranking? If you suspect a change from your answer, explain why.

    Detection

    Correction

    Prevention

    Improve capabilities

28. What are the major changes that the state would like to make in dealing with groundwater contamination?

29. What factors limit the state from making these changes?

30. Does the state consider groundwater to be a problem? If so, what is the nature of the problem and under what circumstances would the state consider the problem to be under control?

31. What types of information on groundwater contamination in other states would be useful to your state?

32. Have you benefitted from other states' information on groundwater contamination? Through what mechanisms?

33. What changes would be required in your state's information management programs to make information listed in your response to #31 available to other states.

G. FEDERAL-STATE RELATIONS

34. How could the federal government be of most assistance to the state on groundwater contamination issues? Please be specific about the particular topics or issues where federal resources would be beneficial.

35. Explain how each of the following federal laws and programs have helped or hindered the states' efforts to address groundwater contamination issues? At a minimum, check the laws and programs the state has used to address groundwater contamination.

A. Laws

1. Environmental Protection Agency

o Clean Water Act (CWA)
Section 104 - [104(a)(5) - water quality surveillance system]
-- Research, Investigation, Training, and Information

Section 106 - Grants for Pollution Control

Section 201 - Grants for Construction of Treatment Works

Section 205(j) - Grants for Water Quality Management Planning

Section 208 - Areawide Waste Treatment

Section 303 - Water Quality Standards and Implementation Plans

Section 402 - National Pollutant Discharge Elimination System

- Safe Drinking Water Act (SDWA)

  Part B - Public Water Systems (Section 1412 - National Drinking Water Regulations)

  Part C - Protection of Underground Sources of Drinking Water
    - Underground Injection Control Program

    - Sole Source Aquifer Program

  Part E - General Provisions
    - Section 1442 -- technical assistance to states and municipalities

    - Section 1443 -- grants for state programs

- Resource Conservation and Recovery Act (RCRA)
  - Subtitle C -- Hazardous Waste Management

  - Subtitle D -- State or Regional Solid Waste Plans

- Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA/Superfund)
  Section 104(c)(3) -- Cooperative Agreements or Contracts with states for remedial actions

- Toxic Substances Control Act (TSCA)

- Uranium Mill Tailings Radiation Control Act (UMTRCA)

- Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)
  Groundwater monitoring studies

  Groundwater modeling -- testing and validation

o Other EPA Laws or Programs (specify)

2. Department of Commerce

- Coastal Zone Management Act of 1972

3. Department of Interior

- Surface Mining Control and Reclamation Act of 1977

4. Other Laws (specify)

- Appalachian Regional Development Act of 1975

- Water Resources Planning Act of 1965

B. Programs

1. Department of Agriculture

- Soil Conservation Service Programs

- Agricultural Stabilization and Conservation Service Programs

2. Department of Commerce

- Grants for public works

- National Bureau of Standards Reference Materials

3. Department of Interior

- Bureau of Indian Affairs Programs

- Bureau of Land Management Programs

- Bureau of Reclamation Programs

- U.S. Geological Survey Programs
  Cooperative programs for Water Resources Investigations

Other USGS programs

- Water Resources Research Institute Cooperative Programs

4. Other (specify)

H. IMPACTS

36. What types of economic and environmental impacts of groundwater contamination have been documented in the state? Check the categories that apply, and if possible, quantify.

    A. Economic Impacts

    - o Decreased value of industrial production
    - o Decreased value of agricultural production
    - o Avoidance of impaired uses through relocation
    - o Decreased values for industrial, agricultural, or residential lands
    - o Damage to materials
    - o Costs of obtaining alternative water supplies
    - o Legal/administrative expenses
    - o Compensation payments
    - o Other (specify)

B. Environmental Impacts:

- Surface water
- Land/soil
- Biota
- Air

C.3 SUBSTANCES WITH STATE STANDARDS OR FEDERAL STANDARDS OR GUIDELINES FOR WATER QUALITY THAT MAY BE APPLIED TO GROUNDWATER

	STATE STANDARDS[a]					FEDERAL STANDARDS AND GUIDELINES (mg/l)					
	Drinking Water		Groundwater Quality			National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
Chemical	States	Range[b] (mg/l)	States	Range[b] (mg/l)	Total No. of States	Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
A. Organic Chemicals											
1. Acenapthene											0.02^c
2. Acrylonitrile	NH	0.035/10 day - 0.003/1 mo.	NH	0.035/10 day - 0.003/1 mo.	1						0.000058^d
3. Alachlor			NY	0.035	1						
4. Aldicarb (Sulfoxide and Sulfone)	CA,NY	0.001-0.007	NY	0.00035	2						
5. Aldrin	CA,IL	Limit of quantification - 0.001	IL,NY,MD,VA	None - 0.001	5						0.000000074^d
6. Amiben			NY	0.0875	1						
7. Atrazine			NY	0.0075	1						
8. Baygon	CA	0.009			1						
9. Benefin			NY	0.035	1						
10. Benzene	CA,FL,NH,NY	0.0007 - .001 S	NM,NH,NY	None detectable - 0.1;S	4	RMCL[e]		—	0.23	0.07	0.00066^d
11. α - Benzene hexachloride (α -BHC)	CA	0.0007			1						
12. β - Benzene hexachloride (β -BHC)	CA	0.0003			1						
13. Benzidine			MD	None	1						0.00000012^d

	STATE STANDARDS[a]					FEDERAL STANDARDS AND GUIDELINES (mg/1)					
	Drinking Water		Groundwater Quality			National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
Chemical	States	Range[b] (mg/1)	States	Range[b] (mg/1)	Total No. of States	Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
A. Organic Chemicals (Continued)											
14. Benzo (a) pyrene			NY	None detectable	1			0.1	0.1	0.025	
15. Bis (2-chloroethyl) ether			NY	0.001	1						0.00003[d]
16. Bromacil (a uracil)			NY	0.0044	1						
17. Bromodichloromethane											0.00019[d,f]
18. Butachlor			NY	0.0035	1						
19. Captan	CA	0.35	NY	0.0175	2						
20. Carbaryl			NY	0.0287	1						
21. Carbofuran	NY	0.015			1			0.100	0.100	0.005	
22. Carbon tetrachloride	CA,FL,NH	0.003 - 0.005; S	MN,NH, NM,NY	0.005 - 0.01; S	5	RMCL[e]		0.2	0.02	—	0.0004[d]
23. Chlordane	CA,IL,NH	0.000055; S	IL,MD NH,NY,VA	None - 0.01; S	6			0.063	0.063	0.008	0.00000046[d]
24. Chlorobenzene											0.488[g]
25. Chloroform			MN,NY	0.1 - 0.2	2						0.00019[d]
26. Demiton			MD	0.0001	1						
27. Di (2-ethyl hexyl) phthalate (DEHP)			NY	0.0042	1						15.0[h]

	STATE STANDARDS[a]					FEDERAL STANDARDS AND GUIDELINES (mg/1)					
	Drinking Water		Groundwater Quality			National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
Chemical	States	Range[b] (mg/1)	States	Range[b] (mg/1)	Total No. of States	Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
A. Organic Chemicals (Continued)											
28. Di-n-butyl phthalate			NY	0.770	1						34.0[h]
29. Diazinon	CA	0.014	NY	0.0007	2						
30. Dibromochloropropane (DBCP)	CA,NH	0.001; 0.00005/ lifetime	NH	0.00005/lifetime	2						
31. Dibromoethane (EDB)	CA,FL	Limit of quantification -0.00002			1						
32. Dicamba			NY	0.00044	1						
33. Dichlorobenzene (m-)	CA	0.02 - 0.13			1						0.04[h]
34. Dichlorobenzene (o-)	CA	0.01 - 0.13			1						0.40[h]
35. Dichlorobenzene (p-)	CA	0.0003 - 0.13	NY	0.0047	2	RMCL[e]					0.40[h]
36. Dichlorodiphenyltrichloroethane (DDT)	IL	0.05	IL,MD,NY,VA	None-0.05	4						0.000000024[d]
37. 1,2-Dichloroethane	CA,FL	0.001-0.003	MN,NM	0.02	3	RMCL[e]					0.00094[d]
38. 1,1-Dichloroethylene (Vinylidiene chloride)	NH	1.0/1 day - 0.07/ lifetime	MN,NH, NM	0.005; 1.0/1 day - 0.07/lifetime	3	RMCL[e]		1.0	0.07	0.07	0.000033[d]
39. 1,2-Dichloroethylene (cis and trans)	CA,NH	Limit of quantification; S	NH	S	2			cis: 4.0 trans: 2.7	0.4 0.27	— —	
40. Dichloromethane (Methylene chloride)	CA,NH	0.004;S	NH	S	1			13.0	1.3	0.15	0.00019d,f

	STATE STANDARDS^{a}					FEDERAL STANDARDS AND GUIDELINES (mg/1)					
	Drinking Water		Groundwater Quality			National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
Chemical	States	Range (mg/1)^{b}	States	Range (mg/1)^{b}	Total No. of States	Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
A. Organic Chemicals (Continued)											
41. 2,4-Dichlorophenol											3.09^{g}
42. 2,4-Dichlorophenoxyacetic acid (2,4-D)	IL	0.01	NY	0.0044	2	0.1					
43. 1,2-Dichloropropane	CA	0.01			1						
44. Dicyclopentadiene (DCPD)											0.112^{i}
45. Dieldrin	CA, IL	Limit of quantification - 0.001	IL, MD NY, VA	None - 0.001	5						0.000000071^{d}
46. Diethyl phthalate											350.0^{g}
47. Diisopropylmethyl phosphonate (DIMP)											0.45^{i}
48. Dimethoate	CA	0.14			1						
49. 2,4-Dimethylphenol	CA	0.4			1						0.40^{c}
50. 1,4-Dioxane	NH	0.02/10 day	NH	0.02/10 day	1			5.68	0.568	—	
51. Dioxins^{j}			MD	None	1						
52. Diphenamide	CA	0.04			1						
53. Diphenyl hydrazine			NY	None detectable	1						0.000042^{d}
54. Dithane			NY	0.00175	1						

	STATE STANDARDS[a]					FEDERAL STANDARDS AND GUIDELINES (mg/1)					
	Drinking Water		Groundwater Quality			National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
Chemical	States	Range[b] (mg/1)	States	Range[b] (mg/1)	Total No. of States	Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
A. Organic Chemicals (Continued)											
55. Endosulfan			MD	0.000003	1						0.074[h]
56. Endrin			MD,NY,VA	None-0.000004	3	0.0002					0.001[h]
57. Ethion	CA	0.035			1						
58. Ethyl Benzene											1.4[h]
59. Ethylene glycol	NH	19.0/1 day	NH	19.0/1 day	1			19.0	5.5	5.5	
60. Ethylene thiourea (ETU)			NY	None detectable	1						
61. Ferbam			NY	0.00418	1						
62. Fluoranthene											0.042[h]
63. Folpet			NY	0.056	1						
64. Formaldehyde								0.030	0.030	—	
65. Gasoline[i]	NH	None	NH	None	1						
66. Guthion			MD,NY	0.00001-0.00044	2						
67. Heptachlor	CA,IL	0.00002-0.001	IL,MD,NY,VA	None-0.001	5						0.00000028[d]
68. Heptachlor epoxide	CA,IL	0.0001 - 0.002	VA	0.001	3						
69. Hexachlorobenzene (HCB)			NY	0.00035	1						0.00000072[d]

Chemical	STATE STANDARDS[a]					FEDERAL STANDARDS AND GUIDELINES (mg/l)					
	Drinking Water		Groundwater Quality			National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
	States	Range[b] (mg/l)	States	Range[b] (mg/l)	Total No. of States	Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
A. Organic Chemicals (Continued)											
70. Hexachlorophene			NY	0.007	1						
71. Hexane (n-)								13.0	4.0	—	
72. Isopropyl N (3-chlorophenyl) cartamates (CIPC)	CA	0.35			1						
73. Kepone			NY	None detectable	1						
74. Lindane (γ-BHC)			IL,MD, NY,VA	None - 0.001	4	0.004					
75. MBAs (Foaming agents)[j]			MN,NY,VA	0.05 - 0.5	3		0.5				
76. Malathion	CA	0.16	MD,NY	0.0001 - 0.007	3						
77. Maneb			NY	0.00175	1						
78. Methoxychlor			NY,VA	0.00003 - 0.35	2	0.1					
79. 2-Methyl - 4 chlorophenoxy-acetic acid (MCPA)			NY	0.00044	1						
80. Methyl ethyl ketone	NH	1.0/10 day	NH	1.0/10 day	1			7.5	0.75	—	
81. Methyl methocrylate			NY	0.007	1						
82. Methyl parathion	CA	0.03	IL,NY	0.0015 - 0.1	3						

	STATE STANDARDS[a]					FEDERAL STANDARDS AND GUIDELINES (mg/1)					
	Drinking Water		Groundwater Quality			National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
Chemical	States	Range[b] (mg/1)	States	Range[b] (mg/1)	Total No. of States	Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
A. Organic Chemicals (Continued)											
83. Mirex			MD	None	1						
84. Nitralin			NY	0.035	1						
85. Naphthalene											NA[k]
86. Oil and Grease[j]			IL,MT,NC VA,WY	Virtually free - 10.0	5						
87. Other hydrocarbons[j]	NH	Prohibited	NH	Prohibited	1						
88. Paraquat			NY	0.00298	1						
89. Parathion	CA	0.03	MD	0.00004	2						
90. Pentachloronitrobenzene (PCNB)	CA	0.0009	NY	None detectable	2						
91. Pentachlorophenol (PCP)	CA	0.03	NY	0.021	2						1.01[g]
92. Petroleum hydrocarbons[j]			VA	1.0	1						
93. Phenols[j]	CA,PA	0.001	IL,MN,NY NC,NM,VA,WY	0.0001-0.100	9						3.5[g]
94. Phorate (also Disulfoton)			NY	None detectable	1						
95. Polychlorinated biphenyls (PCBs)[j]	NH,NY	0.0001; 0.001/1 month - 0.0003/lifetime	MD,MN,NH NM,NY,NC	None - 0.001	6			0.125	0.0125	—	0.00000079[d]

	STATE STANDARDS[a]					FEDERAL STANDARDS AND GUIDELINES (mg/l)					
	Drinking Water		Groundwater Quality			National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
Chemical	States	Range[b] (mg/l)	States	Range[b] (mg/l)	Total No. of States	Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
A. Organic Chemicals (Continued)											
96. Polynuclear aromatic hydrocarbons (PAHs)[j]	NH	0.025/7 day	NH	0.025/7day	1						0.0000028[d]
97. Propachlor			NY	0.035	1						
98. Propanil			NY	0.007	1						
99. Propazine			NY	0.016	1						
100. Pthalate esters[j]			NC	None detectable	1						individual[l]
101. RDX (Cyclonite)											0.03368[i]
102. Simazine			NY	0.07525	1						
103. Styrene (vinyl benzene)			NY	0.931	1						
104. 1,2,4,5- Tetrachlorobenzene											0.038[h]
105. 2,3,7,8-Tetrachlorodibenzo p-dioxin (TCDD)			NY	0.000000035	1						
106. Tetrachloroethane (1,1,1,2- and 1,1,2,2)	CA	0.04	MN,NM	0.02	3						0.00017[d](1,1,2,2)
107. Tetrachloroethylene (or perchloroethylene, PCE)	FL,NH	0.003; S	NH,NM	0.0035 - 0.020	2	RMCL[e]		2.3	0.175	0.020	0.0008[d]
108. Thiram			NY	0.00175	1						

Chemical	STATE STANDARDS[a]					FEDERAL STANDARDS AND GUIDELINES (mg/1)					
	Drinking Water		Groundwater Quality			National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
	States	Range[b] (mg/1)	States	Range[b] (mg/1)	Total No. of States	Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
A. Organic Chemicals (Continued)											
109. Toluene	CA,NH	0.1; 1.0/10 day	NH,NM,MN	15.0; 1.0/10 day	4			21.5	2.2	0.34	14.3[h]
110. Toxaphene			MD,NY	None - none detectable	2	0.005					0.00000071[d]
111. Trichloroethane (1,1,1 and 1,1,2)	CA,FL,NH	0.2-0.3 (1,1,1); S	NH	S	2	RMCL[e] (1,1,1)		—	—	1.0 (1,1,1)	18.4[h] (1,1,1) 0.0006[d] (1,1,2)
112. 1,1,2-Trichloroethylene (TCE)	CA,NH	0.005 - 0.075	MN,NH NM,NY	0.0045 - 0.1; S	5	RMCL[e]		2.0	0.2	0.735	0.0027[d]
113. 2,4,5-Trichlorophenoxyacetic acid (2,4,5-T)			NY	0.035	1						
114. 2,4,5-Trichlorophenoxypropionic acid (2,4,5-TP, or Silvex)			NY	0.00026	1	0.01					
115. Trifluralin			NY	0.035	1						
116. Trihalomethanes[j] (TTHMs)						0.10					
117. Trinitrotoluene (TNT)											0.04424[i]
118. Trithion	CA	0.007			1						
119. Vinyl chloride	CA,FL,NY	0.001 - 0.005	NY	0.005	2	RMCL[e]					0.002[d]
120. Xylenes[j]	CA,NH	0.62; S	NH	S	1			12.0	1.4	0.62	

Chemical	STATE STANDARDS[a]					FEDERAL STANDARDS AND GUIDELINES (mg/l)					
	Drinking Water		Groundwater Quality		Total No. of States	National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
	States	Range[b] (mg/l)	States	Range[b] (mg/l)		Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
A. Organic Chemicals (Continued)											
121. Zineb			NY	0.00175	1						
122. Ziram			NY	0.00418	1						
B. Inorganic Chemicals											
123. Aluminum			MN,NM,WY	0.1-5.0	3						
124. Ammonia			WY	0.02-0.5	1						
125. Ammonia nitrogen			VA	0.025	1						
126. Arsenic	PA	0.01	MN,NM,NY	0.01-0.1	4	0.05					0.0000022[d]
127. Barium			NM,NY	1.0	2	1.0					
128. Beryllium			WY	0.011-1.1	1						0.0000037[d]
129. Boron			AK,IL,MN NM,WY	0.3-5.0	5						
130. Cadmium			IL,NM,NY,VA,WY	0.0004-1.0	5	0.010					0.010[h]
131. Chlorides[j]			MN,NM,NY,VA,WY	25-250	5		250				
132. Chlorine			AK,MD	Not specified-0.01	2						
133. Chromium			NM,NY	0.05	2	0.05					0.050[h] (hexavalent) 170.0[h] (trivalent)

	STATE STANDARDS[a]					FEDERAL STANDARDS AND GUIDELINES (mg/l)					
	Drinking Water		Groundwater Quality			National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
Chemical	States	Range[b] (mg/l)	States	Range[b] (mg/l)	Total No. of States	Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
B. Inorganic Chemicals (Continued)											
134. Cobalt			MO,MN,NM,WY	0.05-1.0	4						
135. Copper	IL	5.0	IL,MO,NY,NM,NM,WY	0.01-1.0	5						1.0[c]
136. Cyanides[j]	IL,PA	0.01 - 0.2	MO,NM,NY,VA IL,MN,WY	0.005-0.025	8						0.200[h]
137. Fluorides[j]	IL,KY,MO,NH PA,TN,WI	1.0 - 2.2	IL,NM,NY,VA	1.4-1.6	10	1.4 - 2.4					
138. Heavy metals[j]			AK	Not specified	1						
139. Iron	IL	1.0	NM,NY,VA	0.01-10	4		0.3				
140. Lead			NM,NY	0.025-0.05	2	0.05					0.050[h]
141. Lithium			VA,WY	2.5	2						
142. Manganese	IL	0.15	NM,NY,VA	0.01-0.5	4		0.05				
143. Mercury			IL,NM,NY,VA	0.00005-0.002	4	0.002					0.000144[h]
144. Molybdenum			MN,NM	1.0	2						
145. Nickel			IL,MN,NM VA,WY	0.05-1.0	5						0.0134[h]
146. Nitrates[j]			NJ,NM,NY	Not specified-10.0	3	10.0 (as N)					
147. Nitrites[j]			NC,VA,WY	0.025-10.0	3						

	STATE STANDARDS[a]					FEDERAL STANDARDS AND GUIDELINES (mg/1)					
	Drinking Water		Groundwater Quality			National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
Chemical	States	Range (mg/1)[b]	States	Range (mg/1)[b]	Total No. of States	Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
B. Inorganic Chemicals (Continued)											
148. $(NO_3 + NO_2)$-N[j]			VA,WY	0.5-100	2						
149. Phosphates[j]			NJ	Not specified							
150. Selenium			NM,NY	0.02-0.05	2	0.01					0.010[h]
151. Silver			IL,NM,NY	0.005-0.05	3	0.05					0.050[h]
152. Sodium	AK,FL,ME	20-250	VA	25-100	4						
153. Sulfates[j]			MN,NM,NY,VA,WY	10-600	5		250				
154. Vanadium			VA,WY	0.1	2						
155. Zinc			MD,NM,NY,VA,WY	0.05-25	5		5.0				5.0[c]
C. Biological Substances											
156. Coliform bacteria	WI	None	MD	200	2	1/100 ml					
D. Radionucleides											
157. Beta particle and photon radioactivity[j]						4 mrem					
158. Gross alpha particle activity[j]						15 pCi/1					
159. Gross beta[j]	PA	1000 pCi/1	IN,IL,MT,VA	50-1000 pCi/1	5						

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Chemical	STATE STANDARDS[a]					FEDERAL STANDARDS AND GUIDELINES (mg/1)					
	Drinking Water		Groundwater Quality			National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
	States	Range[b] (mg/1)	States	Range[b] (mg/1)	Total No. of States	Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
D. Radionucleides (Continued)											
160. Radium 226	PA,WI	None - 3.0	IN,IL,VA	1.0-3.0	5						
161. Radium 226 and 228, combined[j]			NM	30 pCi/1	1	5.0 pCi/1					
162. Radon 222	PA	10									
163. Strontium 90			IN,IL,VA,WY	2.0-10.0	4						
164. Tritium	AK,MT	20,000 pCi/1									
165. Uranium			NM,WY,VA	0.03-5.0	3			—	—	10.0 pCi/1	
E. Other Measures											
166. Alkalinity[j]			VA	10-500	1						
167. ABS (alkyl benzene sulfonate)[j]			PA	0.5	1						
168. CCE (Carbon chloroform extract)[j]			PA	0.2	1						
169. COD (Chemical oxygen demand)[j]			MD	10.0	1						
170. DO (Dissolved oxygen)[j]			MN,MD	1.0-6.0	2						
171. HCO^3 (Bicarbonate)			MN	5.0 meq/1	1						
172. Residual carbonate			AK	1.25	1						
173. RSC (Residual sodium carbonate)			WY	1.25 meq/1	1						

	STATE STANDARDS[a]					FEDERAL STANDARDS AND GUIDELINES (mg/1)					
	Drinking Water		Groundwater Quality			National Drinking Water Regulations		EPA Health Advisories			Ambient Water Quality Criteria for Human Health
Chemical	States	Range[b] (mg/1)	States	Range[b] (mg/1)	Total No. of States	Primary	Secondary	One Day	Ten Day	Long Term (1-2 Yrs)	
E. Other Measures (Continued)											
174. SAR (Sodium absorption ratio)[j]			WY	8.0	1						
175. Specific conductance[j]			MN,MT	<1000 - >15,000	2						
176. TDS (Total dissolved solids)[j]			MN,NJ,NM,VA	250-1000	3		500.0				
177. Total hardness[j]			MN,MD,VA	none-300	3						
178. Turbidity[j]	TN,VA	0.5-2.0/2 day			2	1-5 TU					

a. State standards are listed only if they are more stringent or cover additional substances than standards established by the Federal Safe Drinking Water Act.

Sources of information on State standards are (API, 1983) and the OTA State survey. All Federal standards were established by EPA unless otherwise indicated.

b. All standards are in milligrams per liter (mg/l, equivalent to parts per million) unless otherwise indicated. Other units used include mrem (millirem), pCi/l (picocuries per liter), meq/l (milliequivalents per liter), and TU (turbidity units).

The entries in the range column are of three types.

1) Some entries provide information on the lowest and highest concentrations that the States use as standards. If States use the same standard for a substance, a single value is given. Note that the entries do not distinguish among the different ways that a standard might be applied (e.g., different standards may be applied to different classifications of groundwater).

2) Some entries, such as Federal health advisories (SNARLs), are time-dependent and are expressed in terms of concentration per unit time. "S" represents a State standard that is the same as the SNARL.

3) "Not specified" indicates that a State has a standard but the value was not contained in the information sources.

c. Ambient water quality criteria for human health are theoretically derived based on organoleptic effects (i.e., unpleasant taste and odor; see also footnote g), carcinogenicity (see footnote d), or toxicity (i.e., adverse effects other than cancers, see footnotes g and h). In this case, the value indicated is based on controlling unpleasant taste or odor either of water consumed directly or of water consumed indirectly via aquatic organisms found in ambient waters. Note that there is no demonstrated relationship between unpleasant taste or odor and adverse health effects.

d. The value indicated is based on an increased risk of one additional cancer in one million people exposed (10^{-6} risk level) through ingestion of contaminated water and contaminated aquatic organisms. The water quality criteria document values for 10^{-5} and 10^{-7} risk levels are generally ten times higher and lower than the 10^{-6} risk level, respectively.

According to the EPA Notice of Water Quality Criteria Documents (45 FR 79318, Nov. 28, 1980), for the maximum protection of human health from potential carcinogenic effects due to exposure to this chemical through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentration should be zero (assuming that the chemical's behavior is consistent with the non-threshold concept for carcinogens, see app. H.1). The notice further states that:

- zero concentration may not be attainable at the present time;
- concentrations are thus estimated that may result in an incremental increase of cancer over a lifetime at the 10^{-5}, 10^{-6}, and 10^{-7} risk levels; and

- o the estimated risk range is presented for information purposes and does not represent an EPA judgment on an "acceptable" risk level.

e. Recommended Maximum Contaminant Levels (RMCLs) were proposed on June 12, 1984 (49 FR 24330). Proposed values would result in no known or anticipated adverse health effects with an adequate margin of safety and serve as non-enforceable health goals for public water systems.

f. The value indicated is for the category halomethanes, not for the individual chemical.

g. Different criteria are available for both toxicity and organoleptic effects from ingestion of contaminated water and contaminated aquatic organisms. The value indicated is derived from available toxicity data for the protection of public health. Criteria based on taste and odor data are more stringent than the toxicity level; however, there is no demonstrated relationship between unpleasant tastes and odors and adverse health effects.

h. The criterion indicated is for the protection of human health from the toxic properties (i.e., all adverse effects other than cancers) of the substance through ingestion of contaminated water and contaminated aquatic organisms.

i. Criteria levels shown were established by the Army Medical Bioengineering Research and Development Laboratory.

j. Standard is for a group of chemicals or an indicator of water quality, not a single chemical.

k. "Not available" indicates that a criterion for human health has not been published due to the insufficiency of available data. However, criteria are available for aquatic life.

l. A level is not established for the protection of human health from total phthalate esters. Levels to protect human health from toxic properties of the following individual phthalate esters have been set for ingestion of water and contaminated aquatic organisms:

dimethylphthalate -- 313.0 mg/l
diethylphthalate -- 350.0 mg/l
dibutyl-phthalate -- 34.0 mg/l
di-2-ethylhexyl-phthalate -- 15.0 mg/l

Source: Office of Technology Assessment.

C.4 OTA STATE SURVEY RESPONSES: EXAMPLES OF STRENGTHS, PROBLEMS, AND DESIRED FEDERAL ASSISTANCE FOR EACH STATE

Appendix C.4 documents information summarized in State Strengths and Problems in Programs to Deal With Groundwater Contamination and Desired Federal Assistance, chapter 4. The States' responses to open-ended survey questions about groundwater program strengths and problems, and desired Federal assistance on groundwater protection are listed. The caveats for interpreting survey results, described in OTA State Survey, chapter 4, apply to this appendix; in particular, 1) information in this appendix reflects the views of the State personnel involved in groundwater quality programs who responded to the survey and 2) the fact that only a few States raised a particular issue does not necessarily imply that the issue is not of concern to other States.

	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
ALABAMA			
Sources			
Improve Capabilities		- Insufficient staff expertise - Insufficient resources for enforcement	
Standards		- Lack of groundwater quality standards	
Detection		- Difficulty obtaining cooperation and coordination of efforts to isolate source of contamination when there are several possible sources	
Correction		- Insufficient authority to stop use of contaminated private wells - Difficulty testing buried tanks for leaks after detection of gasoline contamination - Lack of State cleanup fund	
Prevention			

	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
ALASKA			
Sources	- Existence of State permit programs for wastewater discharges, landfills, and solid waste disposal sites		
Improve Capabilities		- Insufficient funding - Insufficient enforcement of State permit program requirements	- Provide funding for enforcement activities - Provide technical assistance for obtaining public support for cleanup efforts
Standards			
Detection			- Provide technical assistance for analyzing hydrogeology and identifying dangerous levels of contamination
Correction			- Provide technical assistance for implementing cleanup technologies, informing public, and developing substitute water supplies
Prevention		- Insufficient programs to regulate hazardous wastes from cradle to grave	

	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
ARIZONA			
Sources			
Improve Capabilities	- Groundwater permit program under development - State legislative support - Integrated program to regulate groundwater quantity and quality for portions of the State and to protect beneficial uses	- Difficulties with Federal programs including Federal-State coordination - Insufficient research and development activities	- Facilitate information transfer - Improve Federal programs related to establishing quality standards, resolving Indian water rights problems, and coordinating Federal groundwater programs
Standards	- State narrative standards for groundwater quality	- Lack of standards for volatile organics - Difficulties with conducting risk assessments	- Accelerate research and development on criteria to support standards and develop toxicological information for volatile organics and risk assessment
Detection		- Insufficient data - Insufficient technical support for laboratory facilities	- Provide funding for data collection - Provide technical assistance for laboratory analysis
Correction			
Prevention			
ARKANSAS			
Sources	- Strong programs for hazardous wastes and contamination problems associated with oil wells		
Improve Capabilities		- Insufficient staff expertise - Insufficient resources for enforcement - Insufficient State legislative support - Insufficient funding - Lack of groundwater strategy	- Train State staff - Establish policy to protect interstate aquifers
Standards			
Detection		- Insufficient enforcement	- Provide funding for data collection
Correction			- Provide funding for correction of existing contamination
Prevention			

	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
CALIFORNIA			
Sources	- Authority to address most sources of contamination	- Insufficient programs and authority to regulate underground storage of non-waste materials	
Improve Capabilities		- Insufficient authority to enforce health advisories - Difficulties with coordination among State agencies	
Standards			- Accelerate research and development on standards for toxics
Detection	- Experienced staff for isolating potential sources of contamination	- Need to improve coordination - Insufficient monitoring - Insufficient data management - Insufficient funding - Insufficient training opportunities	- Provide funding for data collection
Correction	- State program to provide cleanup funds	- Insufficient authority under State water rights doctrine to manage groundwater resources	- Provide additional funding for cleanup under CERCLA - Accelerate research and development on inexpensive treatment techniques
Prevention			- Accelerate research and development on technologies to control more contaminants

COLORADO	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources		- Insufficient program regulations and statutory limitations regarding septic tanks, liquid waste disposal, and inactive/abandoned waste disposal sites	
Improve Capabilities	- On-going effort to evaluate need for program changes	- Industrial opposition to groundwater protection efforts - Insufficient resources for studying problems - Insufficient program regulations and statutory limitations regarding drinking water standards	- Provide funding for development and implementation of State programs - Provide technical assistance
Standards		- Difficulties with Federal criteria for uranium	- Establish Federal drinking water standards for organic chemicals
Detection	- Program under development	- Insufficient funding - Insufficient staff expertise	
Correction			
Prevention			

CONNECTICUT	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Authority to control most sources of groundwater contamination		
Improve Capabilities		- Insufficient research and development activities	- Provide funding for State research and special studies - Provide technical assistance and training on dealing with groundwater problems
Standards	- Water quality standards and classification system	- Inadequate risk assessment of exposure to pollutants	- Establish additional standards for water quality
Detection		- Insufficient funding - Insufficient staff expertise - Insufficient investigation of aquifer characteristics	- Provide funding for data collection
Correction			
Prevention			

DELAWARE	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities		- Insufficient staff expertise - Difficulty attracting and retaining qualified staff - Difficulty gaining cooperation of local governments - Insufficient information for risk assessment	- Provide funding for development and implementation of State programs - Facilitate information transfer on available technology
Standards		- Insufficient toxicology and risk information	- Accelerate research and development on toxicological information and risk assessment
Detection	- Effective mechanisms for coordination of involved agencies	- Technical difficulties in determining relationship between concentrations of contaminants at points of use and sources	- Accelerate research and development on monitoring
Correction		- Inability to handle sufficient numbers of incidents	
Prevention		- Questionable reliability of existing programs for prevention	

FLORIDA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Strong regulatory authority over sources		
Improve Capabilities		- Insufficient staff to implement regulations - Insufficient funding	- Provide technical assistance and staff training
Standards		- Lack of implementable standards	- Accelerate research and development on standards for toxics
Detection		- Insufficient monitoring related to sources, ambient quality, and aquifer characteristics - Insufficient materials and instruments for detection activities	- Provide funding for data collection
Correction		- Inability to handle sufficient numbers of incidents - Inadequate technology for karst environments	- Train State staff on technologies for cleanup
Prevention		- Lack of classification system	

GEORGIA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities	- Groundwater management plan under development	- Problems with slow EPA bureaucracy - Lack of Federal delegation of UIC Program to State	- Provide technical assistance
Standards			
Detection	- Effective coordination - Monitoring program under development		
Correction	- Authority to correct most potential point sources of contamination		
Prevention			

HAWAII	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities		- Insufficient staff - Insufficient funding - Insufficient program coordination	- Facilitate information transfer on toxic substances
Standards		- Insufficient toxicology and risk information	
Detection	- Strong program for monitoring public water supplies	- Insufficient monitoring related to sources and contaminants	
Correction			
Prevention			

IDAHO	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources		- Insufficient regulations and/or guidelines for surface impoundments, mining activities, hazardous waste disposal, subsurface sewage disposal, and soliu waste disposal	
Improve Capabilities		- Insufficient guaranteed long-term funding - Insufficient staff - Insufficient program coordination - Lack of information/education program	- Improve Federal regulations to be more responsive to specific needs of States
Standards		- Lack of groundwater quality standards	
Detection		- Insufficient funds and expertise for geophysical evaluations	- Provide funding for data collection
Correction			- Provide funding for dealing with widespread problems - Provide technical assistance on implementing cleanup actions
Prevention			- Provide funding for implementing federally mandated programs

ILLINOIS	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources		- Lack of regulations for siting or monitoring industrial product storage, production facilities, and pipelines	
Improve Capabilities		- Insufficient funding - Insufficient resources - Lack of groundwater strategy - Insufficient program coordination - Insufficient emphasis on protection	- Provide funding for development and implementation of State programs - Provide technical assistance - Accelerate research and development - Facilitate information transfer
Standards		- Lack of groundwater quality standards	
Detection	- Strong staff capabilities	- Insufficient data - Insufficient facilities - Insufficient authority over water rights and site access - Technical uncertainties associated with data interpretation	
Correction			
Prevention		- Inability to establish sufficient land use controls to protect groundwater - Lack of classification system	

INDIANA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities		- Insufficient funding - Insufficient staff expertise - Insufficient laboratory analytical capability	
Standards			- Accelerate research and development on toxicology and risk assessment
Detection		- Insufficient resources to identify and verify sources of contamination - Insufficient monitoring of sources and groundwater supplies - Inadequate response time for checking private wells for contamination	- Provide funding for data collection - Provide technical assistance for analyzing hydrogeology
Correction		- Insufficient information on groundwater use	- Provide technical assistance for implementing cleanup alternatives
Prevention			

IOWA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Good program to regulate landfills and wastewater treatment facilities	- Insufficient programs to control non-point sources of contamination	
Improve Capabilities		- Insufficient resources - Insufficient data	
Standards			- Accelerate research and development on criteria to support State groundwater standards
Detection		- Difficulties obtaining site access in some cases - Insufficient monitoring of sources	
Correction			- Accelerate research and development on technology for corrective action
Prevention			- Accelerate research and development on control technologies and management practices

KANSAS	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities	- Strong staff capabilities	- Insufficient funding - Difficulty retaining qualified staff - Difficulty obtaining public support	- Modify RCRA to establish more practical approach to delisting, defining hazardous wastes, and approval procedures for State primacy
Standards			- Increase research and development on standards for Priority Pollutants
Detection	- Strong staff capabilities	- Insufficient resources	
Correction		- Difficulties with CERCLA	- Simplify CERCLA procedures to allow States to use funding more readily
Prevention			

KENTUCKY	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources		- Insufficient programs for handling agricultural wastes, household wastes, and some on-site sewage disposal, and for aquifer protection	
Improve Capabilities		- Insufficient funding - Insufficient staff expertise - Insufficient enforcement (over-reliance on self-monitoring) - Lack of groundwater strategy - Insufficient priority for groundwater relative to surface water - Insufficient legislative, public, and industrial support	- Provide funding for staff training, special studies, and development and implementation of State programs - Provide technical assistance - Accelerate research and development on demonstration projects - Establish reasonable national groundwater protection policy - Clarify Federal program requirements and resolve inconsistencies among programs
Standards		- Lack of groundwater quality standards	- Accelerate research and development on standards for toxics
Detection		- Insufficient staff expertise and equipment to characterize aquifers - Insufficient data - Insufficient authority for groundwater under some programs - Insufficient funding	
Correction			- Accelerate research and development on cleanup of on-site waste disposal problems
Prevention			- Accelerate research and development on preventing contamination from on-site waste disposal

LOUISIANA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities	- Program coordination	- Difficulty attracting and retaining staff with sufficient expertise - Insufficient flexibility in Federal regulations to negotiate with industry	- Provide funding for implementation of cooperative programs - Provide technical assistance on geochemistry, toxicology, and statistical analysis
Standards			
Detection			
Correction			
Prevention			

MAINE	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources		- Difficulty addressing widespread sources such as agricultural contaminants and gasoline tank leaks	
Improve Capabilities		- Insufficient staff - Insufficient funding	
Standards			- Establish additional Federal drinking water standards
Detection		- Insufficient data on aquifer characteristics and contamination sources	- Provide funding for data collection
Correction		- Lack of funding and authorization to undertake emergency remedial action	
Prevention			

MARYLAND	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Programs to deal with different sources of contamination		
Improve Capabilities		- Insufficient funding - Difficulty attracting experienced staff	- Provide technical assistance
Standards			
Detection		- Insufficient capabilities to install wells (e.g., lack of equipment) - Technical difficulties - Difficulty obtaining site access	
Correction			
Prevention			

MASSACHUSETTS	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities		- Insufficient funding	- Accelerate research and development on groundwater movement and treatment
Standards			
Detection			
Correction			
Prevention			

MICHIGAN	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities		- Insufficient funding	
Standards		- Lack of standards to limit discharges to groundwater	
Detection		- Insufficient monitoring - Insufficient resources - Difficulties with modeling (e.g., high costs and validation)	- Provide funding for investigations at hazardous waste sites
Correction	- State program for cleanups and setting priorities for cleanup action	- Insufficient funds for cleanup	- Provide technical assistance for public information and public relations on cleanup activities - Support administration of CERCLA program
Prevention		- Lack of non-regulatory approaches to prevention such as environmental impairment liability insurance	

MINNESOTA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Strong programs related to spill reporting and cleanup, acid rain deposition, water well construction, and water well abandonment		
Improve Capabilities		- Insufficient funding - Insufficient staff - Insufficient public understanding	- Establish national program to assist States in program development and implementation
Standards			
Detection		- Technical difficulties demonstrating that a contamination problem is related to a specific source	
Correction			- Provide funding for dealing with nonhazardous waste problems
Prevention			

MISSISSIPPI	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities			- Train State staff
Standards			
Detection	- Monitoring related to regulatory requirements	- Insufficient data on aquifer characteristics	- Provide funding for data collection
Correction			- Provide funding for correction of existing contamination - Provide an information clearinghouse on cleanup activities
Prevention			

MISSOURI	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources		- Difficulty controlling agricultural use of chemicals	
Improve Capabilities		- Insufficient resources for enforcement	- Provide funding for hiring of additional trained staff - Train State staff - Strengthen Federal regulations
Standards			
Detection		- Insufficient monitoring requirements - Insufficient staff and staff training - Insufficient data to describe groundwater flow in karst environments	- Provide funding for data collection and special studies
Correction			- Accelerate research and development on technologies
Prevention		- Insufficient well drilling standards and enforcement	- Provide funding for development of better controls on sources of contamination - Develop controls on contaminant generation, handling, and destruction

MONTANA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources		- Insufficient programs for agricultural sources, pipelines, and fuel storage tanks	
Improve Capabilities	- Enhanced enforceability of programs due to recent development of groundwater permit regulations and quality standards	- Insufficient funding - Insufficient public support	- Provide technical assistance
Standards			
Detection		- Insufficient monitoring related to aquifer characteristics - Insufficient funding - Insufficient authority - Insufficient technical expertise	
Correction		- Insufficient response to complaints	
Prevention		- Insufficient review of projected impacts of development activities on groundwater quality	

NEBRASKA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources		- Insufficient programs for agricultural non-point sources	
Improve Capabilities	- Existence of comprehensive enabling legislation - Broad range of staff expertise	- Insufficient funding - Overlap of agencies' programs and responsibilities - Insufficient research	- Improve funding for CWA, RCRA, and SDWA programs - Provide technical assistance - Accelerate research and development - Facilitate information transfer - Remove Federal incentives that lead to contamination - Allow greater State flexibility in Federal program implementation
Standards			
Detection	- Program coordination under RCRA, UIC, and CWA - Well-equipped laboratory facilities	- Insufficient data base - Insufficient staff for laboratory and investigative activities - Insufficient authority over quality/quantity issues	
Correction		- Insufficient staff for corrective action activities	- Provide technical assistance for implementing cleanup actions
Prevention		- Inability to restrict inappropriate activities in sensitive areas - Lack of properly located and constructed hazardous waste disposal facilities	

NEVADA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Authority to address any source of groundwater contamination		
Improve Capabilities		- Insufficient staff expertise - Insufficient funding	
Standards			- Provide technical assistance on the development and implementation of standards for toxics
Detection			- Provide technical assistance for monitoring and laboratory analysis
Correction			
Prevention			

NEW HAMPSHIRE	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities	- Comprehensive groundwater permit program		- Provide funding for development and implementation of State programs - Provide technical assistance
Standards			
Detection		- Insufficient resources - Insufficient monitoring of sources, especially those associated with industrial waste discharges	- Provide funding for monitoring and laboratory analysis
Correction			
Prevention		- Lack of suitable hazardous waste disposal facilities - Insufficient enforcement of transportation requirements for hazardous wastes	- Provide funding for sole source aquifer protection

NEW JERSEY	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Authority to deal with all types of contamination	- Insufficient programs for storage tanks	
Improve Capabilities		- Insufficient funding	- Provide funding for data collection on hydrogeology for planning and prevention purposes
Standards			- Accelerate research and development on standards for toxics
Detection	- Well-equipped investigation programs	- Insufficient authority - Insufficient monitoring related to sources - Difficulty obtaining qualified staff	- Accelerate research and development on groundwater sampling procedures
Correction		- Inability to handle sufficient numbers of incidents	- Train State staff especially on safety
Prevention			

NEW MEXICO	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Existence of comprehensive regulations to protect groundwater quality from a wide variety of sources - Strong programs for new or newly modified sources	- Insufficient programs related to irrigation practices, sanitary landfills, dumps, hydrocarbon fuel facilities, and septic tanks	
Improve Capabilities	- Program coordination	- Insufficient funding - Insufficient staff - Insufficient programs for information and education - Insufficient public support - Insufficient coordination of selected programs (e.g., for hazardous wastes and groundwater protection) - Insufficient data management	- Provide funding for State program expansion - Provide technical assistance - Expand existing data management programs
Standards		- Insufficient number of numeric standards	
Detection		- Insufficient funding - Insufficient laboratory capabilities	- Provide technical assistance on monitoring and laboratory analysis
Correction		- Difficulty dealing with newly recognized problems (e.g., hydrocarbon fuels) - Difficulty obtaining water rights	- Improve response time under CERCLA
Prevention			

NEW YORK	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources		- Insufficient regulatory control of toxic and hazardous chemical storage and handling at industrial and commercial sites	
Improve Capabilities		- Insufficient regulatory program priorities for protecting critical aquifers - Insufficient funding - Inadequate goals for groundwater protection - State statutory weaknesses - Insufficient legislative support - Insufficient enforcement	- Provide funding for development and implementation of State programs
Standards		- Insufficient toxicology and risk information - Insufficient Federal action on health effects data - Insufficient standards for synthetic organics	- Accelerate research and development on standards for toxics - Establish additional Federal drinking water standards
Detection		- Lack of access to specialized equipment	- Provide funding for data collection - Accelerate research and development on fate of chemicals in groundwater - Accelerate research and development on relationships between land use and groundwater quality
Correction			- Accelerate research and development on aquifer renovation and reclamation procedures
Prevention			- Accelerate research and development on identifying substances that should never be released intentionally into the groundwater system

NORTH CAROLINA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources		- Difficulties dealing with wastewater, sludge, landfills, leaks from storage, and agriculture	
Improve Capabilities		- Insufficient funding - Insufficient manpower - Insufficient groundwater strategy implementation	- Provide funding for development and implementation of State programs - Establish comprehensive groundwater policy - Provide technical assistance on data management
Standards			
Detection			- Accelerate research and development on monitoring
Correction			
Prevention			- Accelerate research and development on facility design alternatives to prevent contamination - Accelerate research and development on alternatives to land disposal

NORTH DAKOTA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Adequate authority under State water pollution law for action if any activities contaminate groundwater		
Improve Capabilities		- Insufficient funding - Insufficient staff expertise - Lack of groundwater strategy	- Provide funding for development and implementation of State programs
Standards			
Detection			- Provide technical assistance for hydrologic analysis
Correction			- Provide technical assistance for implementing cleanup actions
Prevention			

OHIO	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Strong programs for landfills, injection wells, and subsurface percolation	- Insufficient programs for non-hazardous surface impoundments	
Improve Capabilities		- Insufficient staff expertise - Insufficient funding - Lack of groundwater strategy - Insufficient resources for enforcement - Insufficient program coordination	- Provide funding for development of State programs - Provide technical assistance
Standards			
Detection		- Insufficient staff to review all sites - Insufficient monitoring	
Correction		- Insufficient coordination in evaluation and cleanup of problems - Inability to handle sufficient numbers of incidents	
Prevention			

OKLAHOMA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Strong UIC Program - New State funding program for corrective action for abandoned wells likely to purge	- Insufficient programs for some sources including urban runoff and construction	
Improve Capabilities	- Interagency coordination	- Insufficient resources - Insufficient coordinating strategy and use of common criteria - Insufficient funding for monitoring, enforcement, education, and special studies - Insufficient staff expertise	- Continue funding for implementation of UIC Program - Provide technical assistance - Establish program for interstate coordination of large groundwater basins
Standards		- Lack of aquifer-specific groundwater quality standards	
Detection	- Interagency coordination	- Insufficient data - Insufficient equipment and testing facilities - Difficulty attracting and retaining qualified staff	- Provide funding for data collection and monitoring program
Correction			- Provide funding for dealing with widespread problems - Accelerate research and development on oil field waste cleanup
Prevention		- Insufficient promotion of prevention of groundwater contamination	- Provide funding for implementing Best Management Practices - Provide an information clearinghouse for State rules and regulations to prevent contamination

OREGON	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Strong program for on-site waste disposal		
Improve Capabilities	- Strong policy for groundwater protection	- Insufficient funding	- Establish coordinated national policy for groundwater protection - Facilitate information transfer
Standards		- Lack of groundwater quality standards	- Accelerate research and development on toxicology and impacts of organic contaminants
Detection		- Insufficient funding - Insufficient staff resources	- Provide funding for data collection
Correction			
Prevention			

PENNSYLVANIA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities		- Insufficient funding and resources for enforcement activities	- Provide funding for State program development - Train State staff - Improve coordination of Federal activities related to groundwater quality and quantity
Standards		- Lack of groundwater quality standards	
Detection	- Effective mechanism for coordination of State programs	- Inadequate funding and other resources	
Correction			
Prevention			

RHODE ISLAND	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities		- Insufficient staff expertise - Difficulties with program coordination	- Provide funding for development of State programs - Train State staff
Standards			- Accelerate research and development on groundwater standards
Detection	- Monitoring program - Good laboratory analysis capabilities	- Difficulties with coordination - Insufficient funding - Insufficient staff	
Correction		- Insufficient authority for problems that do not qualify under CERCLA or RCRA - Difficulties with coordination among State, Federal, and interstate agencies on selecting remedial approaches - Insufficient funding to deal with contamination from non-hazardous wastes	
Prevention			

SOUTH CAROLINA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities		- Inadequate policy for groundwater protection	- Establish Federal policy for groundwater protection
Standards			
Detection		- Insufficient monitoring of potential sources of contamination - Insufficient data	- Provide funding for data collection
Correction		- Lack of State program to provide funds for cleanup activities	- Accelerate research and development on less costly techniques for cleanup and monitoring - Establish national groundwater policy for correction and prevention - Establish cleanup criteria
Prevention			

SOUTH DAKOTA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities		- Insufficient funding - Insufficient staff expertise	- Provide technical and/or financial assistance for development and implementation of State programs
Standards		- Lack of groundwater quality standards	- Provide technical assistance for establishing and implementing standards
Detection		- Insufficient funding to detect and study most sources of contamination	
Correction		- Insufficient funding to correct most sources of contamination	- Provide funding for correcting existing contamination
Prevention			

TENNESSEE	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Adequate authority for most sources	- Insufficient programs for septic tanks	
Improve Capabilities		- Inadequate enforcement	
Standards			
Detection	- Strong staff capabilities	- Inadequate investigative techniques	
Correction		- Lack of funds for State to take action - Potential for State liability in third-party damage suits	
Prevention		- Insufficient resources to conduct hydrogeologic investigations for siting non-hazardous waste activities	

TEXAS	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Strong programs for RCRA facilities and underground injection control except for Class II wells		
Improve Capabilities	- Strong legislative support for groundwater protection	- Insufficient funding - Insufficient staff expertise - Difficulties obtaining site access and water rights	- Continue funding of RCRA - Facilitate information transfer - Improve functioning of RCRA and UIC Program
Standards			
Detection	- Strong staff capabilities	Insufficient monitoring related to sources (e.g., Class I and II injection wells)	- Provide technical assistance for hydrogeologic analysis, especially of fate and transport of contaminants in the subsurface
Correction	- Extensive regulatory power over corrective action		
Prevention			

UTAH	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Strong programs for some mining operations, abandoned mines, hazardous wastes, and disposal of conventional wastewater	- Insufficient programs for small-scale mining operations	
Improve Capabilities		- Insufficient funding - Insufficient staff training - Insufficient legislative and administrative support - Insufficient strategy for groundwater protection	- Clarify legal interpretations of Federal regulations
Standards			
Detection		- Insufficient monitoring - Difficulties obtaining site access	- Provide funding for data collection and monitoring
Correction		- Lack of State cleanup fund - Inadequate enforcement	- Provide an information clearinghouse on successes in dealing with contamination problems
Prevention			

VERMONT	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Authority to address most types of groundwater contamination problems		
Improve Capabilities		- Insufficient funding	- Provide funding for development and implementation of State programs
Standards			
Detection			
Correction	- Adequate authority		
Prevention			

VIRGINIA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources			
Improve Capabilities		- Insufficient funding - Inadequate staff expertise	- Provide funding to help deal with groundwater contamination
Standards			
Detection			
Correction	- Program for emergency response - Funding program for cleanup of oil spills		
Prevention			

WASHINGTON	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Existence of laws and regulations for many sources	- Insufficient resources - Lack of overall strategy for groundwater protection - Policy conflicts and difficulties with interagency coordination - Insufficient staff expertise	
Standards		- Lack of groundwater quality standards	- Accelerate research and development on standards, toxicology, and risk assessment
Detection			- Provide funding for additional groundwater quality monitoring through USGS - Accelerate research and development on laboratory analysis
Correction		- Insufficient staff expertise	- Establish cleanup criteria
Prevention			

WEST VIRGINIA	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources		- Logistical difficulties in addressing large numbers of dispersed, small facilities	
Improve Capabilities		- Insufficient funding - Priorities given to surface water	- Provide funding for implementation of State programs - Train State staff - Provide an information clearinghouse
Standards			
Detection		- Insufficient funding - Insufficient staff expertise	- Provide technical assistance for hydrogeologic analysis with emphasis on monitoring, statistical treatment of sample results, and migration and fate of contaminants
Correction			
Prevention			

WISCONSIN	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Strong programs for drinking water, landfills, and wastewater	- Insufficient programs to deal with spill prevention, pesticide management, and gasoline storage tanks	
Improve Capabilities		- Insufficient funding - Difficulty obtaining State legislative support - Difficulties with Federal programs	- Provide funding for development and implementation of State programs
Standards		- Lack of numeric groundwater quality standards	- Accelerate research and development on standards - Accelerate development of drinking water advisories for chemicals found in groundwater
Detection			- Provide funding for data collection
Correction			
Prevention		- Insufficient resources for prevention programs	- Improve FIFRA to ensure that pesticides contaminating groundwater are no longer used and that pesticides are tested for contamination potential before marketing

WYOMING	EXAMPLES OF STRENGTHS	EXAMPLES OF PROBLEMS	EXAMPLES OF DESIRED FEDERAL ASSISTANCE
Sources	- Groundwater standards that apply to all potential sources of groundwater contamination		
Improve Capabilities		- Insufficient staff expertise - Insufficient funding	- Provide funding for additional State staff
Standards	- Standards for groundwater quality		
Detection			- Provide funding for laboratory equipment and sampling and testing by private labs
Correction		- Insufficient programs and resources to address problems with older facilities	
Prevention			

Source: Office of Technology Assessment.

C.5 OTA STATE SURVEY RESPONSES: SELECTED STATE ISSUES

This appendix lists State contacts for obtaining information on various topics that may be relevant to the development of national policy initiatives to protect groundwater from contamination. Principal agency contacts named in survey responses are given. The issues presented for each State were selected if the State appeared especially articulate or experienced with the subject, based on its responses to the OTA survey.

STATE/CONTACT	EXAMPLES OF ISSUES
ALABAMA Department of Environmental Management 205-271-7700	- experienced with implementation of Underground Injection Control Program
ALASKA Department of Environmental Conservation, Environmental Sanitation Section 907-465-2640	- experienced with enforcement issues related to wastewater discharges, landfills, and solid waste disposal sites
ARIZONA Department of Health Services, Water Quality Management Section 602-255-1180 Department of Water Resources 602-255-1586	- experienced with development of integrated program for groundwater quality and quantity - recognizes need for Federal assistance on establishing quality standards for groundwater - experienced with strong State support for protecting groundwater resources and quality
ARKANSAS Department of Pollution Control and Ecology, Water Division 501-562-7444	- experienced with brine disposal programs - experienced with enforcement issues related to solid waste - experienced with salt-water contamination in agricultural areas
CALIFORNIA State Water Resources Control Board, Toxics Special Projects 916-322-8401 Department of Health Services, Sanitary Engineering Branch 916-324-2216 Department of Food and Agriculture, Environmental Monitoring and Pest Management 916-322-2395	- experienced with development of programs for pesticides and underground storage tanks - experienced with laboratory certification program - experienced with confidentiality of well log data - recognizes technical inadequacies of RCRA regulations

STATE/CONTRACT	EXAMPLES OF ISSUES
COLORADO Department of Health, Office of Health Protection 303-320-8333	- experienced with development of groundwater protection program - experienced with problems with uranium facilities
CONNECTICUT Department of Environmental Protection, Water Compliance Unit 203-566-2588	- experienced with State water quality standards and classification system - experienced with development of groundwater quality monitoring program - experienced with coordination with USGS
DELAWARE Department of Natural Resources and Environmental Control 302-736-4793	- experienced with development of groundwater protection program - experienced with professional staffing problems - experienced with agricultural, septic system, and salt-water intrusion problems
FLORIDA Department of Environmental Regulation, Groundwater Section 904-488-3601	- experienced with development of groundwater quality monitoring program - experienced with underground storage tank problems - experienced with new State legislation to protect groundwater quality - recognizes need for toxicology information - experienced with karst environments
GEORGIA Department of Natural Resources, Environmental Protection Division 404-656-4713	- experienced with development of groundwater quality monitoring program - experienced with salt-water intrusion - experienced with development of groundwater management plan
HAWAII Department of Health 808-548-6767 Department of Agriculture 808-548-7124 Department of Land and Natural Resources 808-548-7643	- experienced with pesticide problems - recognizes need for toxicology information
IDAHO Department of Health and Welfare, Division of the Environment 208-334-4250	- experienced with development of groundwater management plan - recognizes need for adequate and guaranteed long-term funding - experienced with problems with irrigation injection wells

STATE/CONTACT	EXAMPLES OF ISSUES
ILLINOIS Environmental Protection Agency, Division of Public Water Supplies 217-782-9470	- experienced with statewide mapping of potential for contamination of shallow aquifers by waste-related sources - experienced with use of 208 and 205j funds for groundwater management issues
INDIANA State Board of Health, Division of Water Pollution Control 317-862-9360	- experienced with problems with laboratory analytical capabilities - experienced with problems from insufficient water use information
IOWA Department of Water, Air, and Waste Management 515-281-8692	- experienced with non-point sources of contamination - experienced with statewide inventory of active and abandoned wells - experienced with evaluation of groundwater contamination in karst region of the State - experienced with use of 208 funds for groundwater issues
KANSAS Department of Health and Environment, Bureau of Oil Field and Environmental Geology 913-862-9360	- experienced with implementation of brine disposal program - recognizes technical inadequacies of RCRA regulations
KENTUCKY Department for Environmental Protection 502-564-2150	- experienced with problems with mining activities - experienced with on-site sewage system problems - experienced with State agency coordination issues - recognizes problems with Federal judicial interpretations of SMCRA and CWA (NPDES) - recognizes conflicts and inconsistencies among Federal statutes - experienced with karst environments - experienced with State priorities for surface water rather than groundwater problems
LOUISIANA Department of Natural Resources, Office of Environmental Affairs 504-342-1265	- experienced with industrial sources of contamination - experienced with recharge area mapping - recognizes need for experienced staff
MAINE Department of Environmental Protection, Division of Management Planning 207-289-2437	- experienced with problems with widespread sources including agricultural practices and underground gasoline storage tanks

STATE/CONTACT	EXAMPLES OF ISSUES
MARYLAND Department of Health and Mental Hygiene, Office of Environmental Programs 301-383-7328	- experienced with mapping to assess potential for groundwater contamination - recognizes that CWA transfers surface water contamination problems to groundwater
MASSACHUSETTS Office of Environmental Affairs, Department of Environmental Quality Engineering 617-292-5529	- experienced with salt-water intrusion - experienced with mapping to assess potential for groundwater contamination - experienced with development of comprehensive monitoring program - experienced with development of environmental emergency response plan - experienced with development and implementation of funding program for municipalities to purchase land for aquifer protection - experienced with use of 208 and 205j funds for groundwater protection
MICHIGAN Department of Natural Resources, Groundwater Quality Division 517-373-1947	- experienced with State priority system to rank sites requiring cleanup - experienced with assessing the magnitude of groundwater contamination - experienced with development of draft response and incident tracking procedures - expressed interest in non-regulatory approaches to prevention such as environmental impairment liability insurance - experienced with use of 208 and 205j funds for groundwater protection - recognizes that CWA transfers surface water contamination problems to groundwater - recognizes limitations of Federal funding sources
MINNESOTA Pollution Control Agency 612-296-7339	- experienced with development and implementation of statewide groundwater monitoring network - recognizes need for national program and national goals to assist States
MISSISSIPPI Department of Natural Resources 601-961-5099	- experienced with use of groundwater modeling - experienced with implementation of State Underground Injection Control Program
MISSOURI Department of Natural Resources 314-751-3195	- experienced with karst environments - experienced with need for trained personnel

STATE/CONTACT	EXAMPLES OF ISSUES
MONTANA Department of Health and Environment 406-449-3948	- experienced with development of groundwater permit regulations and quality standards - experienced with problems with dryland farming and saline seeps
NEBRASKA Department of Environmental Control 402-471-2186	- experienced with problems with agricultural sources - experienced with problems over lack of State authority for groundwater quality and quantity interactions - experienced with problems over limited scope of groundwater protection programs - experienced with use of 208 funds for groundwater protection
NEVADA Department of Conservation and Natural Resources 702-885-4670	- experienced with problems with septic tanks
NEW HAMPSHIRE Water Supply and Pollution Control Commission 603-271-3503	- experienced with the development and implementation of a groundwater permit program - experienced with program for annual sampling of water supplies for industrial contaminants and pesticides - experienced with problems due to insufficient personnel - experienced with use of health advisories as drinking water and groundwater quality standards - concerned about interstate groundwater quality
NEW JERSEY Department of Environmental Protection 609-292-1185	- recognizes need for storage tank legislation - experienced with use of State NPDES Program for discharges to groundwater that are both intentional (e.g., from injection wells) and unplanned (e.g., from landfills and lagoons) - experienced with aquifer mapping - experienced with use of more stringent groundwater standards for the ecologically sensitive Pinelands - experienced with use of 208 funds to establish State groundwater program

STATE/CONTACT	EXAMPLES OF ISSUES
NEW MEXICO Health and Environment Department 505-984-0020	- experienced with development and implementation of groundwater quality protection program - experienced with problems with mining and milling facilities, hydrocarbon fuel facilities, and dairies - experienced with use of a priority listing of violations of groundwater quality standards - experienced with use of State groundwater quality standards for selected substances - experienced with problems in obtaining water rights for some corrective action alternatives - experienced with technical deficiencies of liners - experienced with an improvement program for State laboratories - experienced with use of 208 funds for groundwater protection - experienced with problems of surface water contamination being transferred to groundwater
NEW YORK Department of Environmental Control 518-457-3495	- experienced with development of bulk storage program - experienced with trying to target groundwater program to protect key aquifers - experienced with problems with pesticides and fertilizers - experienced with development of groundwater management program - experienced with development of groundwater quality standards for organic chemicals - experienced with use of 208 funds for groundwater protection - experienced with development of groundwater classification system
NORTH CAROLINA Department of Natural Resources and Community Development 919-733-5083	- experienced with development of groundwater protection program - experienced with development of groundwater classification system - experienced with problems with current Federal approach to groundwater protection - experienced with conflicts between groundwater and surface water management
NORTH DAKOTA State Health Department 701-224-2354	- experienced with natural contamination problems - experienced with establishment of State task force to develop groundwater protection strategy

STATE/CONTACT	EXAMPLES OF ISSUES
OHIO Environmental Protection Agency 614-455-8307	- experienced with problems with non-hazardous industrial lagoons - recognizes need for Federal funds specifically designated for groundwater programs
OKLAHOMA Department of Pollution Control 405-271-4677	- experienced with development of program to plug abandoned wells - experienced with problems with oil development and nitrate contamination - recognizes benefits of Underground Injection Control Program - experienced with use of 208 funds for groundwater protection
OREGON Department of Environmental Quality 503-229-6065	- experienced with development and implementation of on-site waste program - experienced with use of 205j and 208 funds for groundwater protection - experienced with use of State NPDES Program to protect groundwater - experienced with adverse effects of nitrate contaminated groundwater on surface water
PENNSYLVANIA Department of Environmental Resources 717-787-2666	- experienced with development of groundwater quality standards - experienced with development of groundwater quality monitoring strategy - experienced with use of 208 funds for groundwater protection - experienced with problems of losing trained personnel to industry - experienced with use of State NPDES Program to protect groundwater quality - recognizes lack of applicability of Sole Source Aquifer Program to State hydrogeologic conditions
RHODE ISLAND Department of Environmental Management 401-277-2234	- experienced with problems with State agency coordination - experienced with strong laboratory analysis program
SOUTH CAROLINA Department of Health and Environmental Control 803-758-5213	- experienced with implementation of analytical assistance program for private well owners - experienced with use of 208 funds for groundwater protection - recognizes need for a comprehensive national policy to protect and improve groundwater quality - experienced with problems of surface water contamination being transferred to groundwater

STATE/CONTACT	EXAMPLES OF ISSUES
SOUTH DAKOTA Department of Water and Natural Resources 605-773-3351	- experienced with development of State groundwater strategy - experienced with use of 208 funds for groundwater protection
TENNESSEE Department of Health and Environment 615-741-7206	- experienced with septic tank problems - experienced with enforcement problems - experienced with use of 205j funds for groundwater protection
TEXAS Department of Water Resources 512-475-2786	- experienced with problems associated with obtaining water use information, water rights, and site access - experienced with development and implementation of Underground Injection Control Program for Class I, III, IV, and V wells
UTAH Department of Natural Resources and Energy 801-533-5771	- experienced with development and implementation of programs for active and abandoned mining operations - experienced with problems of coordinating programs of numerous State agencies
VERMONT Department of Water Resources and Environmental Engineering 802-828-2761	- experienced with development of State groundwater protection strategy - experienced with development of program to protect recharge areas of community drinking water supplies (Aquifer Protection Areas) - experienced with program to monitor dairy water supplies - experienced with development of formal procedures for reporting and handling of groundwater contamination incidents - experienced with use of 205j and 208 funds for groundwater protection - experienced with implementation of State and Federal hazardous waste management programs - experienced with evaluation of groundwater quality of non-community water supplies
VIRGINIA State Water Control Board 804-257-6384	- experienced with program for 24-hour emergency response

STATE/CONTACT	EXAMPLES OF ISSUES
WASHINGTON Department of Ecology 206-459-6704	- experienced with development of groundwater protection strategy - experienced with use of 205j funds for groundwater
WEST VIRGINIA Department of Natural Resources 304-348-5935	- experienced with development of groundwater protection strategy - experienced with program to map recharge areas
WISCONSIN Department of Natural Resources 608-267-9350	- experienced with use of State NPDES Program for groundwater - experienced with development of State groundwater program and legislation - experienced with problems of surface water contamination being transferred to groundwater - experienced with pesticide problems
WYOMING Department of Environmental Quality 307-777-7781	- experienced with development of State groundwater quality standards

Source: Office of Technology Assessment.

Appendix D

Hydrogeologic Investigations of Groundwater Contamination

D.1 INFORMATION ON THE HYDROGEOLOGIC ENVIRONMENT USED IN INVESTIGATIONS: DEFINITION OF TERMS (p. 397)

D.1 INFORMATION ON THE HYDROGEOLOGIC ENVIRONMENT USED IN INVESTIGATIONS: DEFINITION OF TERMS[a]

Term	Definition
TOPOGRAPHIC DATA	Data describing the relief and contour of the land surface.
VEGETATIVE DATA	Information about types and extent of vegetation covering the land surface at and adjacent to the site of interest.
CLIMATIC DATA	Data concerning precipitation, evapotranspiration, and temperature at the site of interest and surrounding region.
1. Precipitation	Precipitation history including spatial distribution, temporal variance, long-term averages, and records of short-term events of great magnitude (e.g., record rainfalls).
2. Evapotranspiration	Movement of water to the atmosphere by evaporation from the soil surface, evaporation from open bodies of water, and transpiration by plants.
3. Site temperature	Temperature ranges for different periods of the year as well as long-term averages.
GEOLOGIC DATA	Data concerning the rock and soil makeup of the hydrologic system including information on the thickness of different units and fracture patterns.
1. Surficial deposits	Unconsolidated deposits resulting from fluvial (i.e., river), lacustrine (i.e., lake), glacial, deltaic, and aeolian (i.e., wind) processes.
2. Subsurface stratigraphy	Describes the geometrical configuration of and temporal relationships among various lenses, beds, and formations of sedimentary origin.
3. Lithology	Describes the sediments or rocks that comprise the hydrogeologic system including mineralogy, grain size, grain shape, and packing of sediments and rock grains.
4. Structural geology	Describes the features produced by rock movement after deposition (e.g., due to consolidation or plate tectonics) including tension cracks (i.e., joints), faults, and folds.

Term	Definition
SURFACE HYDROLOGY DATA	Data concerning the properties, distribution, and movement of water on the land surface.
1. Overland flow	Downgradient flow of surface water to an established surface channel.
2. Stream discharge	Quantity of water flowing through a stream.
3. Stage	Height of the water surface in a stream above an arbitrary zero point.
4. Recurrence interval	Average time (e.g., number of years) that hydrologic events of a given or greater size will be equalled or exceeded.
5. Baseflow discharge	Groundwater discharge contribution to streamflow; also called dry weather flow.
UNSATURATED ZONE DATA	Data concerning the properties, distribution, and movement of water in the unsaturated zone.
1. Unsaturated zone (or Vadose zone)	Zone between the land surface and the water table. Generally, any water contained in the void spaces of this zone is under less than atmospheric pressure; some of the voids contain air (at atmospheric pressure).
2. Water table	Surface separating the saturated and unsaturated zones. At the water table, water pressure is equal to atmospheric pressure. (See Unconfined aquifer, GROUNDWATER HYDROLOGY DATA, below.)
3. Geometry of the unsaturated zone	Describes the location of the upper (land surface) and lower (water table) boundaries of the unsaturated zone, the lateral extent of the zone, and the upper, lower, and lateral bounds of differing heterogeneities within the zone.
4. Hydraulic properties	Properties that control the movement of water through the unsaturated zone.
a. Effective porosity	Ratio of the volume of void space in a volume of rock or soil to the total volume.
b. Permeability	Ease with which a porous medium can transmit a fluid when saturated with that fluid. (It should be noted that permeability is a property of the porous medium and is independent of the fluid characteristics.)

Term	Definition
c. Effective permeability	Ease with which a porous medium can transmit a fluid under pressure (i.e., a hydraulic gradient; see Hydraulic gradient, below) when the pore spaces are also filled with other fluids (e.g., oil or air).
d. Relative permeability	Ratio of the permeability of a porous medium with respect to the fluid phase when two or more phases are present (i.e., solid, liquid, and/or gas) to the permeability.
e. Specific storage	Volume of water released from or taken into storage per unit volume of porous medium when the pressure head (or head) is changed by one unit (see Pressure head, below).
5. Flow parameters	Measurements used to define water movement in the unsaturated zone.
a. Pressure head (or Head)	Height of a column of water that can be supported by water pressure at the point of measurement. At the water table, the pressure head is zero; below the water table, the pressure head is positive; and above the water table, it is negative, reflecting the fact that water in the unsaturated zone is held in the pores by principally surface tension. Negative pressure head is sometimes referred to as tension head or suction head.
b. Hydraulic gradient	Rate of change of pressure head (or head) per unit distance of flow at a given point and in a given direction. In an unconfined aquifer, the hydraulic gradient is defined by the slope of the water table.
c. Fluid saturation	Ratio of the volume of water to the volume of voids in the unsaturated zone. In the saturated zone, the fluid saturation is always 1.0.
6. Recharge/discharge	Inflow and outflow of water to and from the unsaturated zone.
a. Surface water	See SURFACE HYDROLOGY DATA, above.
b. Precipitation/ evapotranspiration	See CLIMATIC DATA, above.

Term	Definition
GROUNDWATER HYDROLOGY DATA	Data concerning the properties, distribution, and movement of water in the saturated zone.
1. Saturated zone	A subsurface zone in which all the voids are filled with water under pressure equal to or greater than that of the atmosphere. Even if the zone contains some gas-filled voids or voids filled with fluids other than water, it is still considered saturated. This zone is separated from the unsaturated zone by the water table.
2. Aquifer characterization	Describes the flow system in terms of the number of aquifers and their extent, depth, thickness, and boundary type (i.e., unconfined, confined, or leaky confined).
a. Aquifer	Geologic material containing sufficient saturated permeable material to transmit and yield significant quantities of water to wells or springs.
b. Unconfined aquifer	An aquifer that is not overlain by relatively impermeable or restricting material so that groundwater levels are free to rise and fall. The top of the aquifer is the water table (i.e., the level to which water will rise in a well penetrating the unconfined aquifer).
c. Confined aquifer	An aquifer that is bounded between relatively impermeable material. In the absence of a freely moving water table, the pressure condition of a confined aquifer is characterized by the piezometric surface (i.e., the artesian equivalent of the water table -- the level to which water will rise in a well penetrating the confining layer). The word confined is synonymous with artesian.
d. Leaky confined aquifer	A confined aquifer that receives or transmits significant quantities of water from/to adjacent formations.
3. Hydraulic parameters of aquifers	Physical properties of aquifers that control groundwater movement.

Term	Definition
a. Storativity	Volume of water released from or taken into storage by an aquifer per unit volume of the aquifer per unit change in head. In a confined aquifer, the storativity is a function of the compressibility of both aquifer materials and water. In an unconfined aquifer, the storativity is mainly a function of gravity drainage or filling of the pores. Storativity is synonymous with storage coefficient. (See also Specific storage, UNSATURATED ZONE DATA, above.)
b. Transmissivity	Rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity is a function of properties of both the porous medium (e.g., permeability and aquifer thickness) and the fluid (e.g., dynamic viscosity and density of water).
c. Primary permeability	Ease with which the porous (unfractured) material in a saturated fractured system can transmit water. (See also Permeability, UNSATURATED ZONE DATA, above.)
d. Secondary permeability	Ease with which fractures can transmit water.
e. Primary porosity	Ratio of void space in a volume of fractured material (excluding the fractures) to the total volume of the material. (See also Effective porosity, UNSATURATED ZONE DATA, above.)
f. Secondary porosity	Ratio of void space in a volume of fractured material (including the fractures) to the total volume.
4. Confining unit geometry	Describes the confining units in the system including numbers, lateral extent, depth, and thickness.
5. Hydraulic parameters of confining units	Physical properties of confining units that control groundwater movement.
a. Hydraulic conductivity	Rate at which water is transmitted through a cross section of unit area, perpendicular to the direction of flow, under a unit change in head. Hydraulic conductivity is a function of the properties of both the porous medium (e.g., permeability) and the fluid (e.g., dynamic viscosity and density of water).

Term	Definition
b. Specific storage	See Storativity, above.
6. Flow parameters	Measurements used to define water movement in the saturated zone.
a. Water levels	Level to which water will rise in a tightly cased well that is not subject to injection or discharge.
b. Hydraulic gradient	See Hydraulic gradient, UNSATURATED ZONE DATA, above.
c. Flow velocity	Average rate at which water moves through pores or fractures.
7. Recharge/discharge	Inflow and outflow of water to and from the groundwater system and between units within the system.
a. Surface water	See SURFACE HYDROLOGY DATA, above.
b. Precipitation contributions	Inflow contribution from precipitation reaching the groundwater system.
c. Confining layer leakage	Inflow to an aquifer from storage released from an adjacent confining layer or from flow from other aquifers through the confining layer.
d. Fracture/matrix flux	Velocity of water through fractures (where water is transmitted quickly) and porous material (where movement of water is slower but storage is greater).
CONTAMINANT TRANSPORT PARAMETERS	Physical and chemical properties of the geologic environment that influence the rate of movement of contaminants through the groundwater system.
1. Distribution coefficient	Describes the relationship between a contaminant's adsorption onto soil or rock and its concentration in surrounding water.
2. Dispersivity coefficients	Describe the capacity of contaminants to spread in water.
3. Flow advection velocities	Rates of water movement.

Term	Definition
4. Relative saturations	Relative portions of the pore space filled by water, air, and/or immiscible fluid contaminants.
5. Cation exchange capacity	Describes the excess of cations in solution adjacent to a charged surface that replaces other cations already absorbed onto that surface.
6. Subsurface mineralogy	Chemical makeup of rocks and soils, which influences the reactivity of contaminants.
7. Ambient water chemistry	Natural chemistry of water, which influences the reactivity between water and contaminants.
8. Microbiology	Characteristics and distribution of micro-organisms in an aquifer.
GROUNDWATER USE	Describes how groundwater at a site of investigation is used.
1. Current usage	Present uses of groundwater including where wells are located, how much water is pumped from each well, what aquifers are being tapped, and what quality of water is needed for each use (e.g., water quality needed for drinking water is higher than for cooling at power plants).
2. Projected Usage	Anticipated future uses of groundwater including well locations, future water needs from wells, what aquifers may be tapped, and what quality of water will be needed for each use.

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[a] The terminology of hydrogeology has evolved and expanded with the development of the science. Further, the field of hydrogeology requires multidisciplinary skills, and terms tend to be used in slightly different ways by different disciplines (e.g., hydrologists, geologists, soil scientists, and chemists). OTA notes that definitions and usage have not yet been fully standardized.

Source: GeoTrans, 1983; Office of Technology Assessment, 1983.

Appendix E

Federal Efforts To Detect Groundwater Contamination

E.1 MONITORING PROVISIONS FOR CATEGORY I SOURCES (p. 405)
E.2 MONITORING PROVISIONS FOR CATEGORY II SOURCES (p. 411)
E.3 MONITORING PROVISIONS FOR CATEGORY III SOURCES (p.424)
E.4 MONITORING PROVISIONS FOR CATEGORY IV SOURCES (p. 426)
E.5 MONITORING PROVISIONS FOR CATEGORY V SOURCES (p. 430)
E.6 MONITORING PROVISIONS FOR CATEGORY VI SOURCES (p. 431)

E.1 MONITORING PROVISIONS FOR CATEGORY I SOURCES

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Subsurface Percolation	Safe Drinking Water Act - Underground Injection Control Program (40 CFR 144 and 146)	Cesspools or other waste receiving devices with open bottoms and sometimes perforated sides (Class V wells). Applies only to units serving 20 or more persons.	Regulations have not been promulgated for Class V wells.	Regulations have not been promulgated for Class V wells.	Regulations have not been promulgated for Class V wells.
Injection Wells - Hazardous Waste	Safe Drinking Water Act - Underground Injection Control Program (40 CFR 144 and 146)[a]	Wells that inject hazardous waste (as defined by RCRA) beneath the deepest formation containing, within one-quarter mile of the well bore, an underground source of drinking water (Class I wells).	Determine whether there is any migration of fluids into underground sources of drinking water.	Monitoring program must include (at a minimum): (1) analysis of injected fluid; (2) installation and use of continuing recording devices to monitor injection pressure, flow rate of fluid, volume of fluid and pressure on annulus; (3) demonstration of mechanical integrity every five years; and (4) wells to monitor migration of fluids into and pressure in underground sources of drinking water (location and number of wells are not specified).	o Monitoring well parameters and frequency of sampling are not specified. o Injected fluids are to be analyzed at sufficient intervals to yield representative data about their characteristics.
		Wells that inject hazardous waste (as defined by RCRA) into or above a formation containing, within one-quarter mile of the well bore, an underground source of drinking water (Class IV wells).	Regulations have not been promulgated for Class IV wells.	Regulations have not been promulgated for Class IV wells.	Regulations have not been promulgated for Class IV wells.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Wells that release any hazardous substances, pollutants, or contaminant (as defined by CERCLA).	o To provide preliminary assessment of the nature and extent of the release.	o Collection of samples is minimized except in situations where there is an apparent risk to the public.	o Not specified.
			o To determine the source and dispersion of the hazardous substance.	o Not specified. Monitoring is part of an immediate removal.	o Not specified.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Injection Wells - Hazardous Waste (Continued)	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300) (Continued)		o To determine the nature and extent of the problem.	o Sufficient infomation is to be collected to determine the necessity for and proposed extent of remedial action.	o Not specified.
			o To monitor effectiveness of remedial action.	o Not specified. Assurance must be provided by the State to cover these activities.	o Not specified.
Injection Wells - Non-Hazardous Waste	Safe Drinking Water Act - Underground Injection Control Program (40 CFR 144 and 146)	Wells that inject waste beneath the deepest formation containing, within one-quarter mile of the well bore, an underground source of drinking water (Class I wells)	Same as objective for hazardous waste injection wells that inject beneath the deepest underground sources of drinking water.	Same as requirements for hazardous waste injection wells that inject beneath the deepest underground sources of drinking water.	Same as requirements for hazardous waste injection wells that inject beneath the deepest underground sources of drinking water.
Injection Wells - Non-Waste	Safe Drinking Water Act - Underground Injection Control Program (40 CFR 144 and 146)	Wells used in connection with oil and gas production which inject fluids (Class II wells). Includes wells used for enhanced recovery, for storage of liquid hydrocarbon, and for wells where injected fluids are brought to the surface and may be combined with waste waters from gas plants.	Same as objective for hazardous waste injection wells that inject beneath the deepest underground sources of drinking water.	o Monitoring program must include (at a minimum): (1) monitoring of injected fluids; (2) observation of injection pressure, flow rate and cumulative volume; and (3) demonstration of mechanical integrity every 5 years. o Hydrocarbon storage and enhanced recovery wells may be monitored on a field or project basis (rather than individually).	o Nature of injected fluids is to be monitored at sufficient intervals to yield representative data about their characteristics. o Observation frequencies are specified for different types of wells (fluid disposal wells-weekly; enhanced recovery operations-monthly; injection of liquid hydrocarbons-daily). Observations are to be recorded at reasonable intervals of no greater than 30 days.
		Wells used for extraction of minerals (Class III wells). Includes mining of sulfur by Frasch process, in-situ production of uranium and other metals, and solution mining of salts or potash.	Same as objective for hazardous waste injection wells that inject beneath the deepest underground sources of drinking water.	o Monitoring program must include (at a minimum): (1) monitoring of injected fluids; (2) monitoring of injection pressure and either flow rate or volume; and (3) demonstration of mechanical integrity every 5 years.	o Nature of injected fluids is to be monitored at sufficient intervals to yield representative data about their characteristics.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Injection Wells - Non-Waste (Continued)	Safe Drinking Water Act - Underground Injection Control Program (40 CFR 144 and 146) (Continued)			o Class III wells may be monitored on a field or project basis. o Groundwater monitoring is required where injection is into a formation containing water with less than 10,000 mg/l TDS. Monitoring wells must be completed into injection zone and any underground sources of drinking water above injection zone that may be effected. Wells must be located to detect any excursion of injection fluids, process byproducts, or formation fluids outside the mining area. o In areas subject to subsidence or collapse where injection wells penetrate an underground source of drinking water, an adequate number of wells must be completed to detect any movement of injection fluids.	o Provisions specify monitoring of injection pressure, flow, or volume on a semi-monthly basis (or metering and daily recording of injected and produced volumes as appropriate). o Groundwater monitoring and monitoring of fluid level in injection zone are required semi-monthly (water quality parameters are not specified). o If wells are required in areas subject to subsidence or collapse, monitoring is required on a quarterly basis (water quality parameters are not specified).
		Wells not included in Catgories I, II, III, and IV (Class V wells). Examples of Class V wells include artificial recharge wells, and cooling water or air conditioning return flow wells.	Regulations have not been promulgated for Class V wells.	Regulations have not been promulgated for Class V wells.	Regulations have not been promulgated for Class V wells.
Land Application - Wastewater	Clean Water Act - Section 201 (40 CFR 35; 41 FR 6190, 1/11/76)	Wastewater land treatment processes (includes slow rate, rapid infiltration, and overland flow methods).	Protect groundwater used as drinking water supply and/or other designated uses as appropriate and prevent irrevocable damage to groundwater.	Regulations specify that groundwater monitoring requirements will be established on a site-specific basis. Requirements must include provisions for monitoring the effect on native groundwater.	Requirements are established on a site-specific basis.
Land Application - Wastewater Byproducts	Clean Water Act - Section 405 (40 CFR 257)	Sewage sludge application (includes agricultural, forest and land reclamation utilization, and dedicated land disposal).	No monitoring requirements are established by the regulations.	No monitoring requirements are established by the regulations. Groundwater monitoring may be required on a site-specific basis by the regulatory authority to ensure compliance with groundwater criteria.	No monitoring requirements are established.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Land Application - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)[b]	Land treatment of hazardous wastes (as defined by RCRA).	A three part monitoring program is established:		
			o Detect any contamination of groundwater due to leakage from a facility.	o Detection Monitoring Program - implemented when permit is issued and there is no indication of leakage. Program is continued through post-closure period. Exemption may be granted if there is no potential for migration of liquid from the facility to the uppermost aquifer through post-closure period. - Background water quality levels for monitoring parameters must be based on data from quarterly sampling of wells upgradient from the site for one year. - Number, location, and depth of wells are specified in the facility permit. Wells must yield groundwater samples from the uppermost aquifer that represent the quality of background water not affected by the facility and the quality of water at a specified compliance point. - If monitoring indicates a statistically significant increase of any parameter over the background level, a compliance monitoring program must be implemented (e.g., all wells must be sampled for 375 hazardous constituents (Appendix VIII, 40 CFR 261) to determine the concentrations of these constituents present in groundwater; see below) or it must be demonstrated that the statistically significant increase is the result of an error or is due to another source.	o Parameters are specified in the facility permit (include indicator parameters, waste constituents, or byproducts). Each monitoring well is to be analyzed for specified parameters at least semiannually. o Groundwater flow rate and direction in the uppermost aquifer are to be determined at least annually.
			o Determine whether the groundwater protection standard specified in the permit is being met. (continued on next page)	o Compliance Monitoring Program - implemented when hazardous constituents are detected at a specified compliance point and for a specified compliance period. - A groundwater protection standard must be specified in the facility permit. Standard includes: (i) list of hazardous constituents to be monitored;	o Parameters are specified in the groundwater protection standard (in the facility permit). Each monitoring well is to be analyzed for specified parameters at least quarterly.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Land Application – Hazardous Waste (Contd.)				(ii) concentration limits for each constituent based on: background level; Maximum Contaminant Levels for 14 constituents established by the National Interim Drinking Water Regulations (if higher than background); or an alternative concentration limit (established on a site-specific basis); and (iii) a specified point of compliance and compliance period (includes the active life of the facility and the closure period). - If monitoring indicates that the groundwater protection standard is not being met, a corrective action program must be undertaken or it must be demonstrated that the protection standard is being exceeded due to an error or another source.	o Groundwater flow rate and direction in the uppermost aquifer are to be demonstrated at least annually. o Samples from each monitoring well are to be analyzed for 375 hazardous constituents (Appendix VIII, 40 CFR 261) at least annually.
			o Demonstrate the effectiveness of corrective action measures taken at a facility (see app. G.1 for corrective action requirements under Subtitle C of RCRA).	o Corrective Action Monitoring Program - implemented when compliance monitoring indicates that the groundwater protection standard is exceeded. Program is to be continued until levels of hazardous constituents in groundwater are reduced below the concentration limit specified in the protection standard. Monitoring program may be based on the requirements for a compliance monitoring program and must be as effective as that program.	o Parameters and frequency may be based on the requirements for a compliance monitoring program and must be as effective as that program.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Land application facilities that release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	Same as requirements for hazardous waste injection wells under CERCLA.	Same as requirements for hazardous waste injection wells under CERCLA.	Same as requirements for hazardous waste injection wells under CERCLA.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Land Application – Non-Hazardous Waste	Clean Water Act – Section 404 (40 CFR 30)	Disposal sites for dredged or fill material.	No monitoring requirements are established.	No monitoring requirements are established for groundwater.	No monitoring requirements are established for groundwater.

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[a] RCRA and SDWA have overlapping jurisdiction for injection wells used to dispose of hazardous wastes. A permit-by-rule approach has been instituted to coordinate the requirements of both programs. Under this approach, an owner or operator of such a well must comply with all applicable SDWA technical requirements pursuant to the Underground Injection Control Program and certain RCRA administrative requirements. See 40 CFR 144.14.

[b] The monitoring requirements presented in the table are for permitted facilities. EPA has also promulgated interim status requirements for these facilities which must be met until a final permit is issued. The interim status monitoring requirements specify the installation of at least one upgradient well and three downgradient wells to determine initial background concentrations of certain parameters and to determine whether waste constituents have entered the groundwater. Groundwater monitoring requirements can be waived by an owner or operator if there is low potential for waste migration (EPA approval of the waiver is not required). See 40 CFR 265.

Source: Office of Technology Assessment.

E.2 MONITORING PROVISIONS FOR CATEGORY II SOURCES

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Landfills - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)[a]	Landfills used for the disposal of hazardous wastes (as defined by RCRA).	Three part monitoring program is established: o Detect any contamination of groundwater due to leakage from a facility.	o Detection Monitoring Program - implemented when permit is issued and there is no indication of leakage. Program is continued through post-closure period. Exemption may be granted if there is no potential for migration of liquid from the facility to the uppermost aquifer through post-closure period or if facilities use double liners and leak detection systems. - Background water quality levels for monitoring parameters must be based on data from quarterly sampling of wells upgradient from the site for one year. - Number, location, and depth of wells are specified in the facility permit. Wells must yield groundwater samples from the uppermost aquifer that represent the quality of background water not affected by the facility and the quality of water at a specified compliance point. - If monitoring indicates a statistically significant increase of any parameter over the background level, a compliance monitoring program must be implemented (e.g., all wells must be sampled for 375 hazardous constituents (Appendix VIII, 40 CFR 261) to determine the concentration of those constituents present in groundwater; see below) or it must be demonstrated that the statistically significant increase is the result of an error or is due to another source.	o Parameters are specified in the facility permit (include indicator parameters, waste constituents, or byproducts). Each monitoring well is to be analyzed for specified parameters at least semiannually. o Groundwater flow rate and direction in the uppermost aquifer are to be determined at least annually.
			o Determine whether the groundwater protection standard specified in the permit is being met.	o Compliance Monitoring Program - implemented when hazardous constituents are detected at a specified compliance point and for a specified compliance period.	

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Landfills - Hazardous Waste (Continued)				- A groundwater protection standard must be specified in the facility permit. Standard includes: (i) list of hazardous constituents to be monitored; (ii) concentration limit for each constituent based on: background level; Maximum Contaminant Levels for 14 constituents established by the National Interim Drinking Water Regulations (if higher than background); or an alternative concentration limit (established on a site-specific basis); and (iii) a specified point of compliance and compliance period (includes the active life of the facility and the closure period). - If monitoring indicates that the groundwater protection standard is not being met, a corrective action program must be undertaken (see app. G.2) or it must be demonstrated that the protection standard is being exceeded due to an error or another source.	o Parameters are specified in the groundwater protection standard (in the facility permit). Each monitoring well is to be analyzed for specified parameters at least quarterly. o Groundwater flow rate and direction in the uppermost aquifer are to be determined at least annually. o Samples from each monitoring well are to be analyzed for 375 hazardous constituents (Appendix VIII, 40 CFR 261) at least annually.
			o Demonstrate the effectiveness of corrective action measure taken at a facility (see app. G.2 for corrective action requirements under Subtitle C of RCRA).	o Corrective Action Monitoring Program - implemented when compliance monitoring indicates that the groundwater protection standard is exceeded. Program is to be continued until levels of hazardous constituents in groundwater are reduced below the concentration limit specified in the protection standard. Monitoring program may be based on the requirements for a compliance monitoring program and must be as effective as that program.	o Parameters and frequency may be based on the requirements for a compliance monitoring program and must be as effective as that program.
	Toxic Substances Control Act - Section 6 (40 CFR 761)	Chemical waste landfills used for the disposal of PCBs at concentrations of 50 ppm and above.	To determine baseline groundwater quality data.	o Groundwater must be sampled prior to commencement of operations. If underlying earth materials are homogeneous, impermeable, and uniformly sloping in one direction, only three wells are required. o No groundwater monitoring is required during active life or after closure of facility (surface water monitoring is required).	o Sampling frequency is not specified. o Parameters must include (at a minimum) PCBs, pH, specific conductance and chlorinated organics.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Landfills - Hazardous Waste (Continued)	Comprehensive Environmental, Response Compensation, and Liability Act (40 CFR 300)	Landfills that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	o To provide preliminary assessment of the nature and extent of the release.	o Collection of samples is to be minimized except in situations where there is an apparent risk to the public.	o Not specified.
			o To determine the source and dispersion of the hazardous substance.	o Not specified. Monitoring may be part of an immediate removal.	o Not specified.
			o To determine the nature and extent of the problems.	o Sufficient information is to be collected to determine the necessity for and proposed extent of remedial action.	o Not specified.
			o To monitor effectiveness of the remedial action.	o Not specified. Assurance must be provided by the State to cover these activities.	o Not specified.
Landfills - Sanitary	Resource Conservation and Recovery Act - Subtitle D (40 CFR 257)	Sanitary landfills defined as facilities which pose no reasonable probability of adverse effects on health or the environment from disposal of solid waste (as defined by RCRA).	No requirements established.	o No monitoring requirements are established. o Groundwater monitoring may be required by State solid waste programs. Federal requirements for State programs recommend the establishment of monitoring requirements (see 40 CFR 256.22).	No requirements established.
	Comprehensive Environmental Response,Compensation, and Liability Act (40 CFR 300)	Sanitary landfills that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
Open Dumps (including illegal dumping) - Waste	Resource Conservation and Recovery Act - Subtitle D (40 CFR 257)	Open dumps defined as facilities which do not meet the criteria for sanitary landfills under RCRA.	Same as requirements for sanitary landfills under Subtitle D of RCRA.	Same as requirements for sanitary landfills under Subtitle D of RCRA.	Same as requirements for sanitary landfills under Subtitle D of RCRA.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Open Dumps (including illegal dumping) - Waste (Continued)	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Open dumps that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
Residential Disposal	Federal Insecticide, Fungicide, and Rodenticide Act - Section 19 (40 CFR 165)	Burial of small quantities of pesticide containers in open fields (containers which held organic or metallo-organic pesticides except organic mercury, lead, cadmium, or arsenic compounds).	No requirements established.	No requirements established.	No requirements established.
Surface Impoundments - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Surface impoundments used for the treatment, storage or disposal of hazardous waste (as defined by RCRA).	Same as requirements for hazardous waste landfills under Subtitle C of RCRA.	Same as requirements for hazardous waste landfills under RCRA.	Same as requirements for hazardous waste landfills under RCRA.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Surface impoundments that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
Surface Impoundments - Non-Hazardous Waste	Surface Mining Control and Reclamation Act (30 CFR 816 and 817)	Impoundments defined as all water, sediment, slurry, or other liquid or semi-liquid holding structures and depressions, either naturally formed or artificially built. Structures may be temporary or permanent. Applies to all surface and underground coal mining operations.	To determine the impacts of the mining operation on the hydrologic balance within the permit and adjacent areas.	o Groundwater monitoring plan must be included in a permit application which provides for the monitoring of parameters that relate to the suitability of the groundwater for current and approved post-mining land uses and to objectives for protection of the hydrologic balance. Monitoring site locations must be specified. o Monitoring of a particular water-bearing stratum may be waived by the regulatory authority if it can be demonstrated that it is not a stratum which serves as an aquifer which significantly ensures the hydrologic balance of the cumulative impact area (the area, including the permit area, within which impacts resulting from the proposed operation may interact with the impacts of all anticipated mining).	o Groundwater monitoring plan must specify parameters and sampling frequency. o At a minimum, total suspended solids, pH, total iron, total manganese, and water levels shall be monitored. o Samples must be taken and analyzed quarterly at each monitoring location. Additional monitoring may be required by the regulatory authority.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Surface Impoundments - Non-Hazardous Waste (Continued)	Federal Land Policy and Management Act[b] - Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23). Covers minerals such as coal, phosphate, asphalt, sodium, potassium, sand, stone, gravel and clay.	Impoundments used for the treatment or control of runoff and drainage during mining operations on Federal lands.	No requirements established.	No requirements established.	No requirements established.
	- U.S. Mining Laws (43 CFR 3800). Cover locatable minerals such as gold, silver, lead, iron and copper.	Not explicitly mentioned in the regulations. However, impoundments are part of mining operations. Applies only to Federal lands.	No requirements established.	No requirements established.	No requirements established.
	- Geothermal Steam Act (30 CFR 270 and BLM Operational Order No. 4).	Pits and sumps used to retain all materials and fluids necessary to drilling, production, or other operations on Federal lands.	o To determine existing water quality. o To ensure that operations are conducted in compliance with regulations and orders.	o No specific requirements are established for pits and sumps. Regulations state that monitoring of environmental impacts may be conducted by the use of aerial surveys, inspections, periodic samplings, continuous recordings, or other methods specified on a site-specific basis. o Data must be collected for a period of at least one year prior to production.	o Specified by the regulatory authority on a site-specific basis.
Waste Tailings	Federal Land Policy and Management Act - Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23)	Not explicitly mentioned in the regulations. However, waste tailings are part of mining operations. Applies only to Federal lands.	Same as objective for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Waste Tailings (Continued)	- U.S. Mining Laws (43 CFR 3800)	Not explicitly defined in the regulations, but disposal of waste tailings is mentioned as part of a mining operation.	Same as objective for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.
	Uranium Mill Tailings Radiation Control Act[c] - Active Sites (40 CFR 192)	Disposal areas covered by the regulations containing waste tailings from uranium processing activities. Such areas include the region within the perimeter of an impoundment or pile.	Same as requirements for hazardous waste surface impoundments under Subtitle C of RCRA.	Same as requirements for hazardous waste surface impoundments under RCRA except: - molybdenum and uranium are added to the list of hazardous constituents in Appendix VIII, 40 CFR 261; - additional concentration limits for radioactivity are specified as part of the groundwater protection standard; - detection monitoring program must be completed within one year; and - alternative concentration limits which are established (as part of the groundwater protection standard) are as low as reasonably achievable after considering practicable corrective actions, and that, in any case, the concentration levels for specified parameters are specified at all points at a greater distance than 500 meters from the edge of the disposal area and/or outside the site boundary.	Same as requirements for hazardous waste surface impoundments under RCRA.
	Uranium Mill Tailings Radiation Control Act - Inactive Sites (40 CFR 192)	Processing sites designated by DOE containing residual radioactive materials at which all or substantially all of the uranium was produced for sale to a Federal agency prior to Jan. 1, 1971.	o To establish background groundwater quality.	o Monitoring program may be conducted. It should be sufficient to meet the objective through one or more upgradient wells.	No requirements established.
			o To identify the presence and movement of contamination associated with the tailings piles.	o Monitoring should assess the location of contaminants in groundwater, the rate and direction of movement of contaminated groundwater, and its relative contamination. Also, an assessment should identify the attenuative capacity of the unsaturated and saturated zones to determine the extent of contaminant movement.	

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Waste Piles - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Waste piles used for the treatment or storage of hazardous wastes (as defined by RCRA).	Same as objective for hazardous waste landfills under Subtitle C of RCRA.	Same as requirements for hazardous waste landfills under Subtitle C of RCRA.	Same as requirements for hazardous waste landfills under Subtitle C of RCRA.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Waste piles that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as objective for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
Waste Piles - Non-Hazardous Waste	Surface Mining Control and Reclamation Act (30 CFR 816 and 817)	Refuse piles containing coal mine waste (includes coal processing waste and underground development waste). Applies to all surface and underground coal mining operations.	Same as objective for non-hazardous waste surface impoundments under SMCRA.	Same as requirements for non-hazardous waste surface impoundments under SMCRA.	Same as requirements for non-hazardous waste surface impoundments under SMCRA.
	Federal Land Policy and Management Act - Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23)	Not explicitly mentioned in the regulations. However, waste piles are part of mining operations. Applies only to Federal lands.	Same as objective for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.
	- U.S. Mining Laws (43 CFR 3800)	Not explicitly defined in the regulations, but waste piles are mentioned as part of a mining operation.	Same as objective for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.
Materials Stockpiles	Federal Insecticide, Fungicide, and Rodenticide Act (40 CFR 165)	Storage of packages and containers of pesticides.	To assure minimal environmental insult.	o No mandatory monitoring requirements are established. o An environmental monitoring system should be considered in the vicinity of storage facilities. o Samples from the surrounding groundwater should be collected as appropriate.	Not specified.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Graveyards	—	—	—	—	—
Animal Burial	—	—	—	—	—
Aboveground Storage Tanks - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Aboveground tanks used for the treatment or storage of hazardous wastes (as defined by RCRA).	To ensure the tank is being operated according to design.	o No requirements are established for groundwater monitoring. o Monitoring of tank operation is required to meet objective including data on pressure and temperature, and observations of construction material and area surrounding the tank. o Procedure for emptying and inspecting tank must be established.	o No requirements are established for groundwater monitoring. o Monitoring pressure and temperature at least once each operating day is required (if tank is uncovered, the level of waste inside must be inspected). o Construction materials of tank must be inspected at least weekly. o Area surrounding the tank must be inspected at least weekly to detect obvious signs of leakage (e.g., dead vegetation). o Frequency of inspections involving emptying of tank is not specified (must be based on the waste, construction materials of tank, corrosion or erosion protection used, and corrosion or erosion observed).
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Storage tanks that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as objective for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
	Toxic Substances Control Act (40 CFR 761)	See TSCA requirements, below, for hazardous waste containers.	Same as objective for hazardous waste containers under TSCA.	Same as requirements for hazardous waste containers under TSCA.	Same as requirements for hazardous waste containers under TSCA.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Aboveground Storage Tanks - Non-Hazardous Waste	—	—	—	—	—
Aboveground Storage Tanks - Non-Waste	Clean Water Act - Section 311 (40 CFR 112)	Onshore and offshore facilities with aboveground capacities of greater than 1,320 gallons of oil (or single tanks with capacities greater than 660 gallons).[d]	To ensure the integrity of the tank.	o No requirements are established for groundwater monitoring. o The Spill Prevention Control and Countermeasure (SPCC) Plan must discuss provisions for integrity testing of the tank and for observations of the facility operation for upsets in plant effluent discharges which could cause an oil spill.	Not specified.
	Hazardous Liquid Pipeline Safety Act (49 CFR 195)	Storage of hazardous liquids (as defined by HLPSA) incidental to their movement by pipeline or affecting interstate or foreign commerce. Regulations explicitly define aboveground "breakout tanks" which are used to relieve surges in a hazardous liquid pipeline system or to receive and store hazardous liquid transported by a pipeline. Requirements do not apply to Federal facilities.[e]	To ensure the integrity of the tank.	No requirements are established for groundwater monitoring.	Each tank must be inspected at least once a year.
Underground Storage Tanks - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Covered underground tanks used for the treatment or storage of hazardous waste as defined by RCRA.	Regulations have not been promulgated.	Regulations have not been promulgated.	Regulations have not been promulgated.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Storage tanks that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as objective for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
Underground Storage Tanks - Non-Hazardous Waste	—	—	—	—	—
Underground Storage Tanks - Non-Waste	Clean Water Act - Section 311 (40 CFR 112)	Onshore facilities with underground storage capacities equal to or greater than 42,000 gallons.	To ensure the integrity of the tank.	o No requirements are established for groundwater monitoring. o The Spill Prevention Control and Countermeasure (SPCC) Plan must discuss provisions for regular pressure testing and for observations of the facility operation for upsets in plant effluent discharges which could cause an oil spill.	Not specified.
Containers - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Containers used for the storage of hazardous wastes (as defined by RCRA).	To ensure containers are not leaking and spill containment system has not deteriorated.	o No requirements are established for groundwater monitoring. o Containers and storage areas must be inspected.	o No requirements are established for groundwater monitoring. o Inspections must be conducted at least weekly.
	Toxic Substances Control Act - Section 6 (40 CFR 761)	Containers used to store PCBs at concentrations of 50 ppm and above. Container means any package, can, bottle, bag, barrel, drum, tank or other device.	No requirements established.	o No requirements are established for groundwater monitoring. o Containers must be inspected for leaks.	o No requirements are established. o Inspections must be conducted at least once every 30 days.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Containers that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as objective for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Containers - Non-Hazardous Waste	—	—	—	—	—
Containers - Non-Waste	Federal Insecticide, Fungicide, and Rodenticide Act (40 CFR 165)	Pesticide containers.	See objective for materials stockpiles under FIFRA.	See requirements for materials stockpiles under FIFRA.	See requirements for materials stockpiles under FIFRA.
Open Burning and Detonation Sites	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Open burning and detonation of waste explosives.[f]	Regulations have not been promulgated.	Regulations have not been promulgated.	Regulations have not been promulgated.
	Federal Insecticide, Fungicide, and Rodenticide Act (40 CFR 165)	Open burning of small quantities of combustible pesticide containers which held organic or metallo-organic pesticides (except organic mercury, lead, cadmium or arsenic compounds).	Same as objective for residential disposal (burial) under FIFRA.	Same as requirements for residential disposal (burial) under FIFRA.	Same as requirments for residential disposal (burial) under FIFRA.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Sites which release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as objective for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Radioactive Disposal Sites	Atomic Energy Act (10 CFR 60)[g]	Geologic repositories for high-level radioactive wastes.	To ensure that geotechnical design parameters are confirmed and to ensure that appropriate action is taken to inform NRC of changes needed in design to accommodate actual field conditions encountered.	At a minimum, measurements shall be made of rock deformations and displacement, changes in rock stress and strain, rate and location of water inflow into subsurface areas, changes in groundwater conditions, rock pore pressures including those along fractures and joints, and the thermal and thermochemical response of the rock mass as a result of development and operations of the geologic repository.	Not specified.
	Atomic Energy Act (10 CFR 61)[h]	Disposal sites for low-level radioactive wastes.	To provide basic (preoperational) environmental data on the site, to evaluate the potential health and environmental impacts during construction and operation, and to evaluate the long-term effects and need for mitigative measures.	o Preoperational monitoring must provide information about the ecology, meteorology, climate, hydrology, geology, geochemistry, and seismology of the disposal site over a twelve month period. o Monitoring during construction and operation must be capable of providing early warning of releases of radionuclides from the sites before they leave the site boundary. o Post-operational monitoring system must be based on the operating history and the closure and stabilization of the site and must be capable of providing early warning releases of radionuclides from the site before they leave the site boundary.	o Not specified. o Not specified. o Not specified.

[a] The monitoring requirements presented in the table are for permitted facilities. EPA has also promulgated interim status requirements for these facilities which must be met until a final permit is issued. The interim status monitoring requirements specify the installation of at least one upgradient well and three downgradient wells to determine initial background concentrations of certain parameters and to determine whether waste constituents have entered the groundwater. Groundwater monitoring requirements can be waived by an owner or operator if there is low potential for waste migration (EPA approval of the waiver is not required). See 40 CFR 265.

[b] The Federal Land Policy and Management Act (FLPMA) of 1976 (P.L. 94-579) requires that public lands be managed in a manner that will protect the quality of environmental values. In addition, there are a number of laws regulating certain activities on Federal lands. The mining regulations are authorized by both the FLPMA and the specific mining laws and are thus presented together in this table. Note that regulations for the Geothermal Steam Act were redesignated, with minor revisions, as 43 CFR 3260 on Sept. 30, 1983.

[c] The requirements presented in this table are the Health and Environmental Protection Standards promulgated by EPA (40 CFR 192, 48 FR 45926, Oct. 7, 1983 and 48 FR 590, Jan. 5, 1983). The NRC has also promulgated licensing requirements for uranium mill tailings (10 CFR 30, 40, 70 and 150).

[d] Facilities include those engaged in drilling, producing, gathering, storing, processing, refining, transferring, distributing or consuming oil and oil products. Oil is defined as oil of any kind or in any form, including but not limited to petroleum, fuel oil, sludge, oil refuse, and oil mixed with wastes other than dredged spoil.

[e] Hazardous liquids include petroleum, petroleum products, and anhydrous ammonia.

[f] Waste explosives include waste which has the potential to detonate and bulk military propellants which cannot safely be disposed of through other modes of treatment. Regulations for permitted facilities have not been promulgated. Interim status regulations for open burning and detonation do not establish groundwater monitoring requirements.

[g] The requirements presented are those established by NRC for high-level radioactive wastes; these requirements are proposed regulations. See 46 FR 35280, July 8, 1981. EPA has also published proposed health and environmental standards. See 47 FR 58196, December 29, 1982.

[h] The requirements presented are those established by NRC for low-level radioactive waste sites. EPA is also required to establish health and environmental standards for such sites; standards have not yet been promulgated by EPA.

Source: Office of Technology Assessment.

E.3 MONITORING PROVISIONS FOR CATEGORY III SOURCES

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Pipelines — Hazardous Materials	Hazardous Liquid Pipeline Safety Act (49 CFR 195)	Pipelines used to transport hazardous liquids (includes petroleum, petroleum products, and anhydrous ammonia).	To ensure the integrity of the pipeline.	o No requirements established for groundwater monitoring. o All new pipelines or relocated, replaced or otherwise changed pipelines must undergo hydrostatic testing prior to use.	No requirements established for groundwater monitoring.
	Comprehensive Environmental Response, Compensation and Liability Act (40 CFR 300)	Pipelines that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	o To provide preliminary assessment of the nature and extent of the release.	o Collection of samples minimized except in situations where there is an apparent risk to the public.	o Not specified.
			o To determine the source and dispersion of the hazardous substance.	o Not specified. Monitoring may be part of an immediate removal.	o Not specified.
			o To determine the nature and extent of the problem.	o Collection of sufficient information to determine the necessity for and proposed extent of remedial action.	o Not specified.
			o To monitor effectiveness of the remedial action.	o Not specified. Assurance must be provided by the State to cover these activities.	o Not specified.
Pipelines - Non-Hazardous Materials	—	—	--	—	—
Materials Transport and Transfer Operations — Hazardous Materials and Waste	Hazardous Materials Transportation Act (49 CFR 171)	The transportation of hazardous materials and hazardous waste (as defined by HMTA) by rail car, aircraft, vessel and motor vehicles used in interstate and foreign commerce (and motor vehicles used to transport hazardous waste in intrastate commerce).	No requirements established for groundwater.	No requirements established for groundwater.	No requirements established for groundwater.

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Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Materials Transport and Transfer Operations — Hazardous Materials and Waste (Continued)	Comprehensive Environmental, Response, Compensation, and Liability Act (40 CFR 300)	Transport-related accidents that release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	Same as objectives for pipelines under CERCLA.	Same as requirements for pipelines under CERCLA.	Same as requirements for pipelines under CERCLA.

Source: Office of Technology Assessment.

E.4 MONITORING PROVISIONS FOR CATEGORY IV SOURCES

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Irrigation Practices	Clean Water Act - Section 208 (40 CFR 35, Subpart G) [a]	Return flows from irrigated agriculture.	Determine the impact of the source.	o No specific requirements established. o Groundwater monitoring can be undertaken by a State if it is established as a priority in the State's annual work program submitted to EPA.	No requirement established.
Pesticide Applications	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Agriculturally related non-point sources of pollution.	Same as objective for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.
	Federal Insecticide, Fungicide, and Rodenticide Act	Application of certain pesticides which may cause unreasonable adverse effects on the environment.	No requirements established.	No requirements established.	No requirements established.
Fertilizer Applications	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Agriculturally related non-point sources of pollution.	Same as objective for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.
Animal Feeding Operations	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Runoff from manure disposal areas and from land area used for livestock.	Same as objective for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.
De-icing Salts Application	—	—	—	—	—
Urban Runoff	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Urban stormwater runoff systems.	No requirements established.	No requirements established.	No requirements established.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Percolation of Atmospheric Pollutants	—	—	—	—	—
Mining and Mine Drainage - Surface Mining	Clean Water Act - (Section 208 (40 CFR 35, Subpart G)	Mine-related sources of pollution including mine runoff from new, active, and abandoned surface and underground mines.	No requirements established.	No requirements established.	No requirements established.
	Federal Land Policy and Management Act [b]				
	- Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23)	Mining of minerals such as coal, phosphate, asphalt, sodium, potassium, sand, stone, gravel and clay (on Federal lands).	No requirements established.	No requirements established.	No requirements established.
	- U.S. Mining Laws (43 CFR 23)	Mining of minerals such as gold, silver, lead, iron and copper (on Federal lands).	No requirements established.	No requirements established.	No requirements established.
	Surface Mining Control and Reclamation Act (30 CFR 816)	Surface mining of coal.	Determine the impacts of the mining operation on the hydrologic balance within the permit and adjacent areas.	o Groundwater monitoring plan must be included in a permit application which provides for the monitoring of parameters that relate to the suitability of the groundwater for current and approved postmining land uses and to objectives for protection of the hydrologic balance. Monitoring site locations must be specified. Monitoring is conducted during operations and reclamation activities (until performance bond release). (Continued next page)	o Groundwater monitoring plan must specify parameters and sampling frequency. o At a minimum, total dissolved solids or specified conductance (corrected to 25°C), pH, total iron, total manganese, and water levels shall be monitored. (Continued next page)

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Mining and Mine Drainage - Surface Mining (Continued)	Surface Mining Control and Reclamation Act (30 CFR 816) (Continued)			o Monitoring of a particular water-bearing stratum may be waived by the regulatory authority if it can be demonstrated that it is not a stratum which serves as an aquifer which significantly ensures the hydrologic balance of the cumulative impact area (the area, including the permit area, within which impacts resulting from the proposed operation may interact with the impact of all anticipated mining).	o Samples must be taken and analyzed quarterly at each monitoring location. Additional monitoring may be required by the regulatory authority.
	Surface Mining Control and Reclamation Act (40 CFR 874 and 875)	Lands and water which were mined (covers coal mining and mining of minerals and materials other than coal) or which were affected by such mining, waste banks, processing or other methods prior to Aug. 3, 1977.	No requirements established.	No requirements established.	No requirements established.
Mining and Mine Drainage - Underground Mining	Clean Water Act - Section 208 (CFR 35, Subpart G)	Mine-related sources of pollution including mine runoff from new, active, and abandoned surface and underground mines.	No requirements established.	No requirements established.	No requirements established.
	Federal Land, Policy and Management Act				
	- Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23)	Mining for minerals such as coal, phosphate, asphalt, sodium, potassium, sand, stone, gravel and clay (on Federal lands).	Same as objective for surface mining under these laws.	Same as requirements for surface mining under these laws.	Same as requirements for surface mining under these laws.
	- U.S. Mining Laws (43 CFR 3800)	Mining of minerals such as gold, silver, lead, iron, and copper (on Federal lands).	Same as objective for surface mining under these laws	Same as requirements for surface mining under these laws.	Same as requirements for surface mining under these laws.

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Mining and Mine Drainage - Underground Mining (Continued)	Surface Mining Control and Reclamation Act (30 CFR 817)	Underground mining of coal.[c]	Same as objective for surface mining under SMCRA.	Same as requirements for surface mining under SMCRA.	Same as requirements for surface mining under SMCRA.

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[a] 40 CFR 35, Subpart G are the regulations for State grants for Water Quality Planning, Management, and Implementation. Although the Clean Water Act is directed at the protection of surface waters, some States have chosen to include groundwater quality programs in their water quality management plans. Such plans are required by the regulations to indicate recognition that groundwater and surface water intermix.

[b] The Federal Land Policy and Management Act (FLPMA) of 1976 (P.L. 94-579) requires that public lands be managed in a manner that will protect the quality of environmental values. In addition, there are a number of laws regulating certain mining activities on Federal lands. The mining regulations are authorized by both the FLPMA and the specific mining laws and are presented together in this table.

[c] Applies to surface effects of underground mining.

Source: Office of Technology Assessment.

E.5 MONITORING PROVISIONS FOR CATEGORY V SOURCES

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Production Wells - Geothermal and Heat Recovery	Federal Land Policy and Management Act - Geothermal Steam Act (30 CFR 270 and BLM Operational Order No.4)[a]	Wells used for the development of geothermal steam (on Federal lands)	o Determine existing water quality. o Ensure that operations are conducted in compliance with regulations and orders.	o Data must be collected for a period of at least one year prior to production. o No specific requirements for pits and sumps. Regulations state that monitoring of environmental impacts may be conducted by the use of aerial surveys, inspections, periodic samplings, continuous recordings or other methods specified on a site-specific basis.	o Specified by the regulatory authority on a site-specific basis.
Production Wells - Water Supply	—	—	—	—	—
Other Wells - Monitoring Wells, Non-Waste	—	—	—	—	—
Other Wells - Exploration Wells, Non-Waste	Federal Land Policy and Management Act - Mineral Leasing Act of 1920 and Materials Act of 1947 (40 CFR 23)	Exploration wells used in mining operations for minerals such as coal, phosphate, asphalt, sodium, potassium, sand, stone, gravel, and clay.	No requirements established.	No requirements established.	No requirements established.
Construction Excavation	Clean Water Act - Section 208 (40 CFR 35 Subpart G)[b]	Construction activity related to sources of pollution.	o Determine the impact of the source.	o No specific requirements established. o Groundwater monitoring can be undertaken by a State if established as a priority in the State's annual work program submitted to EPA.	o No requirements established.

[a] Note that regulations for the Geothermal Steam Act were redesignated, with minor revisions, as 43 CFR 3260 on Sept. 30, 1983.

[b] 40 CFR 35, Subpart G are the regulations for State grants for Water Quality Planning, Management, and Implementation. Although the Clean Water Act is directed at the protection of surface waters, some States have chosen to include groundwater quality programs in their water quality management plans. Such plans are required by the regulations to indicate recognition that groundwaters and surface water intermix.

Source: Office of Technology Assessment.

E.6 MONITORING PROVISIONS FOR CATEGORY VI SOURCES

Source	Statutory Authority	Definition of Source	Monitoring Objective	Design of Monitoring System	Parameters and Sampling Frequency
Groundwater — Surface Water Interactions	Clean Water Act — Section 208 (40 CFR 35, Subpart G)[a]	Intermixing of groundwater and surface water.	Determine the impact of the source.	o No specific requirements established. o Groundwater monitoring can be undertaken by a State if established as a priority in the State's annual work program submitted to EPA.	No requirements established.
Natural Leaching	Reclamation Act	Natural salt deposits affecting undergound water supplies.	No requirements established.	No requirements established.	No requirements established.
Salt-water Intrusion	Clean Water Act — Section 208 (40 CFR 35, Subpart G)[a]	Salt-water intrusion into rivers, lakes, and estuaries resulting from reduction of freshwater flow from any cause including groundwater extraction.	Same as objective for groundwater-surface water interactions under CWA.	Same as requirements for groundwater-surface water interactions under CWA.	Same as requirements for groundwater-surface water interactions under CWA.
	Coastal Zone Management Act	Salt-water intrusion	No requirements established.	No requirements established.	No requirements established.

[a] 40 CFR 35, Subpart G are the regulations for State grants for Water Quality Planning, Management, and Implementation. Although the Clean Water Act is directed at the protection of surface waters, some States have chosen to include groundwater quality programs in their water quality management plans.

Source: Office of Technology Assessment.

Appendix F

Corrective Action: Technologies and Other Alternatives

F.1 TECHNICAL CONDITIONS DETERMINING THE APPLICABILITY OF CORRECTIVE ACTION ALTERNATIVES (p. 433)
F.2 NON-TECHNICAL CONDITIONS DETERMINING THE APPLICABILITY OF CORRECTIVE ACTION ALTERNATIVES (p. 439)
F.3 APPLICATION OF CORRECTIVE ACTION ALTERNATIVES TO SOURCES (p. 443)

F.1 TECHNICAL CONDITIONS DETERMINING THE APPLICABILITY OF CORRECTIVE ACTION ALTERNATIVES[a]

Condition	Containment	Withdrawal	Treatment	In-situ Rehabilitation	Management Options
Aquifer Type Unconfined/perched Partially confined Confined Homogeneous Nonhomogeneous	All containment measures designed to limit or halt the lateral migration of contaminants (e.g., slurry walls, sheet pile, geomembrane cutoff, clay cutoff) must be tied into a naturally occurring horizontal stratum of low permeability to be effective. Ease of construction/excavation will depend on aquifer type and geologic setting.	Effectiveness of methods depends on degree of nonhomogeneity, complexity, and in particular, hydraulic continuity of the aquifer.	Indirect. Conditions determine applicability insofar as before treatment can be applied, groundwater must be withdrawn and transported to a surface treatment unit. (see Withdrawal).	Aquifer type may be major limiting factor if not unconfined/perched and homogeneous. Effectiveness of biological and chemical degradation is dependent on ability to inject, control, and withdraw reagents, which may be difficult or impractical in nonhomogeneous aquifers. Effectiveness of natural process restoration and water table adjustment is constrained in confined, partially confined, and nonhomogenous aquifers.	Poses no constraint on applicability of methods.
Saturation Conditions Unsaturated zone Saturated zone	Hydraulic barriers are not applicable in unsaturated zone. Clay cutoffs are not commonly applied in saturated zone because de-watering would be required during installation. Otherwise, saturation conditions are not limiting for the use of containment methods.	Pumping and gravity drainage are not applicable in the unsaturated zone. Gas venting is not applicable in the saturated zone. Otherwise, saturation conditions are not limiting for methods.	Indirect. Conditions determine applicability insofar as before treatment can be applied, groundwater must be withdrawn and transported to a surface treatment unit (see Withdrawal). Although removal of unsaturated zone water is not practical by pumping or gravity drainage, soil and unsaturated zone water could be excavated and treated by techniques not requiring the water to be entirely in the liquid phase (e.g., air and steam stripping, chemical and biological detoxification).	Saturation conditions are unlikely to pose major constraint on applicability of methods. Effectiveness of degradation methods may be restricted to use in the unsaturated zone (e.g., if dependent on aerobic conditions).	Poses no constraint on applicability of methods.

Condition	Containment	Withdrawal	Treatment	In-situ Rehabilitation	Management Options
Flow System Recharge Storage Discharge	Nature of flow system is important in choice of technologies. Use of methods in recharge areas may require some form of surface water control to prevent the contained area from filling and overflowing with recharge water. In discharge areas, underdrainage may be required below liners to dissipate uplift uplift pressures.	Flow system generally poses no major technical constraints on methods. However, water-level fluctuations (e.g., due to seasonal variations) that can change the rate or direction of flow, leakage among layers in multi-layer flow systems, and downward migrating flow systems pose additional uncertainties.	Indirect. Condition determines applicability insofar as before treatment can be applied, groundwater must be withdrawn and transported to a surface treatment unit (see Withdrawal).	Flow system is not a major constraint. However, in recharge areas, degradation reagents may be difficult to control after injection; this is of particular concern if reagents are in themselves contaminants. In discharge areas, water table adjustment is typically more difficult; natural processes may bring contaminants to surface water bodies.	Generally poses no constraint on applicability of methods. May be important for monitoring options.
Depth 0-5m Up to 20m Over 20m	Depth is major limiting factor for methods, in large part arising from equipment limitations. Practical depths for material barriers will vary among individual technologies but are generally in the vicinity of 20m. While technically feasible, generally little experience has been gained at depths greater than 20m (one exception is sheet piles which appear practical to depths of 40m).	Depth poses no major technical constraints unless excavation is required (e.g., gravity drainage, excavation). Excavation costs increase rapidly at depths greater than about 5m and very rapidly greater than about 20m. Applicability of gravity drainage is limited to about 3-7 m.	Indirect. Condition determines applicability insofar as before treatment can be applied, groundwater must be withdrawn and transported to a surface treatment unit (see Withdrawal).	Depth is likely to constrain applicability of degradation techniques; there is limited experience with degradation below about 5m and it is not likely to be practical below 20m because of controllability problems.	Poses no constraint on applicability of methods.
Areal extent $<1000\ m^2$ Up to 0.1 km^2 Up to 10 km^2 Over 10 km^2	While areal extent in itself poses no technical limitations, the use of material barriers tends to be practically restricted to areas less than 1000m^2; exceptions include slurry walls (up to 10 km^2) and liners (up to 0.1 km^2). Experience with other methods tends to be limited to upwards of 0.1 km^2, except for natural containment which can exceed 10 km^2 depending on site conditions.	While areal extent in itself poses no technical limitations, little experience has been gained with methods in areas as large as 10 km^2.	Indirect. Condition determines applicability insofar as before treatment can be applied, groundwater must be withdrawn and transported to a surface unit (see Withdrawal).	Areal extent is likely to constrain applicability of all methods because of controllability factors (except natural process rehabilitaton) to areas less than 10 km^2 but little experience available.	Poses no technical constraint on applicability of methods but large areas (e.g., greater than 0.1 km^2) may practically restrict use.

Condition	Containment	Withdrawal	Treatment	In-situ Rehabilitation	Management Options
Volume $<35m^3$ Up to 1000 m^3 Up to 10^6m^3 $>10^6m^3$	While volume of contaminated groundwater in itself poses no technical limitations, the use of methods is practically restricted to volumes less than $1000m^3$ because of cost considerations. Exceptions include slurry walls, geomembranes, and liners for which experience has been gained upwards to 10^6m^3. Volumes naturally contained will depend on site conditions.	While volume of contaminated groundwater in itself poses no major technical limitations, little experience has been gained with methods for volumes greater than about 10^6m^3. An exception is withdrawal enhancement which appears practically applicable for volumes only up to about $1000m^3$.	Indirect. Condition determines applicability insofar as before treatment can be applied, groundwater must be withdrawn and transported to a surface treatment unit (see Withdrawal). Feasibility of methods is directly related to design flow rates rather than volumes.	While volume of contaminated groundwater in itself should pose no major technical limitations, there is little experience dealing with volumes in excess of about $1000m^3$ (except for natural process restoration). Higher volumes could lead to controllability problems.	Poses no technical constraint on applicability of methods but large volumes (e.g., greater than $1000m^3$) may practically restrict use.

Condition	Containment	Withdrawal	Treatment	In-situ Rehabilitation	Management Options
Predominant Geologic Setting Sedimentary Crystalline Coarse-grained Fine-grained	Geology is major limiting factor if rocks are sedimentary or crystalline. The presence of rocks, boulders, etc., poses difficult excavation problems for most methods (exceptions include hydraulic barriers and grouting, the latter also being dependent on fracture and/or adsorptive characteristics of the rock). Coarse-grained materials generally pose no limitations, except for natural containment. Fine-grained materials restrict use of grouting, hydraulic barriers, and sheet piles.	Geology is a major limiting factor for certain methods. In general, areas of high transmissivity may render withdrawal options impractical due to high fluid handling requirements. (i) Only gravity drainage and gas venting are generally unconstrained by the presence of sedimentary or crystalline rock; applicability of other methods depends on nature of fracture system and other features of the geologic formation. Excavation is not generally applicable in sedimentary or crystalline rock. (ii) Coarse-grained materials generally pose no limitations except for withdrawal enhancement, which depends on features of the geologic formation. (iii) Unconsolidated, fine-grained materials of low permeability restrict effectiveness of pumping and gravity drainage; only excavation can proceed without major constraint in fine-grained materials.	Indirect. Condition determines applicability insofar as before treatment can be applied, groundwater must be withdrawn and transported to a surface treatment unit (see Withdrawal).	Effectiveness of methods in general will depend on site conditions. Fine-grained materials which constrain flow control and areas of poor drainage or heterogeneity may adversely affect methods. Non-homogeneous areas may not allow for sufficient contact between reagents and contaminated materials.	Poses no constraint on applicability of methods.

Condition	Containment	Withdrawal	Treatment	In-situ Rehabilitation	Management Options
Climate					
Air temperature Below freezing 0° to 20°C Above 20°C	Methods requiring construction/excavation cannot be performed efficiently during periods when the ground is frozen.	Under frozen conditions, pumping and gravity drainage require special surface handling procedures for fluids in certain cases. Excavation is often not practical.	All treatment facilities must be protected (i.e., heated) in temperatures below freezing. In addition, low temperatures (e.g., 0°-20°C) seriously impair air and steam stripping (volatility reduced) and biological transformations (rate reduced) if water is also allowed to decrease in temperature.	Temperatures below freezing require special handling procedures for injectants and for the protection of piping; water table adjustment may be feasible, depending on site conditions. Low temperatures reduce rates of chemical and biological transformation.	Poses no constraint on applicability of methods.
Rainfall					
Evapotranspiration greater than precipitation Precipitation greater than evapotranspiration	Methods requiring construction and/or excavation require surface water controls if precipitation exceeds evapotranspiration. Run-on and runoff controls and surface seals are essential for slurry wall.	Rainfall is generally not a major limiting factor for methods. Excavation may require surface water controls if precipitation exceeds evapotranspiration.	Indirect. Condition determines applicability insofar as before treatment can be applied, groundwater must be withdrawn and transported to a surface treatment unit (see Withdrawal).	Rainfall is probably not a constraint in general but could be depending on site conditions. Applicability of natural rehabilitation may be limited if natural recharge is limited.	Poses no constraint on applicability of methods.
Special Construction Considerations	Emplacement of barriers (e.g., membranes and liners) has risks associated with barrier damage during handling and installation. Specially designed equipment is needed for slurry wall construction using a vibrating beam. There is difficulty in obtaining water-tight interlocks with sheet piles.	Specially designed equipment and materials are required for withdrawal enhancement.	Equipment size is determined by flow rate and nature and amount of contaminants to be removed. Sophisticated controls are required for ultrafiltration. Semi-permanent equipment is required for air and steam stripping.	Means to inject reagents into the soil is required.	Construction considerations vary depending on such factors as availability of alternative sources of water, availability of transportation/distribution/delivery system, and nature of the source of contamination.

Condition	Containment	Withdrawal	Treatment	In-situ Rehabilitation	Management Options
Contaminant Type and Concentration	Contaminant category poses major constraint on applicability of some methods. Contaminant-specific evaluations will be required to assure compatibility of contaminant (at high concentrations) and physical barrier materials. Aromatic hydrocarbons and other volatiles (e.g., volatile halogens) are least amenable to containment methods. Generally, if contaminants are of low concentration, the type of contaminant may not be critical. Hydrodynamic controls do not depend on contaminant type, assuming no contact is made. The handling and disposal of any excavated materials could influence the use of this option.	Limitations posed by contaminant category vary among specific methods. Geochemistry and other associated factors that affect partitioning of contaminants between the soil, rock, and water may affect efficiency of both excavation and pumping methods. Handling and disposal of excavated materials and associated contaminants could constrain the use of this option. Withdrawal enhancement is applicable only to organics. Relatively dilute concentrations become increasingly less cost-effective to pump.	Contaminant category poses major constraint on applicability of methods because any method tends to address specific contaminant categories. Treatment is also limited if mixtures of contaminants are present and if concentrations are changing rapidly (discontinuously) over time. No methods are available for some pathologicals (viruses) and radionuclides (little experience with treatment). Treatment costs are also sensitive to mass and volume of material to be treated. Rate of process is limited by low concentrations.	Limitations posed by contaminant category vary among specific methods. All methods are generally applicable to organics. Effectiveness of water table adjustment and natural process restoration is very contaminant specific and could be limited (e.g., if contaminants are strongly adsorbed or in separate fluid phases). Degradation methods are best suited when single contaminants are present. Biological degradation appears applicable only to certain categories of organics and typically is not efficient for low concentrations. No degradation method appears applicable to pathogens. No method is applicable to radionuclides.	Generally poses no constraint on applicability of methods. Applicability of methods is dependent on public perception about the nature and severity of the problem.

[a] Based on Woodward-Clyde Consultants, Inc., 1983.

Conversion factors:
.305 x feet to obtain meters (m)
4047 x acres to obtain square meters (m^2)
2.590 x square miles to obtain square kilometers (km^2)
.028 x cubic feet to obtain cubic meters (m^3)

Source: Office of Technology Assessment.

F.2 NON-TECHNICAL CONDITIONS DETERMINING THE APPLICABILITY OF CORRECTIVE ACTION ALTERNATIVES[a]

Condition	Containment	Withdrawal	Treatment	In-situ Rehabilitation	Management Options
Environmental/social side-effects	Major potential side-effects are associated with the continued presence and possible leakage of contaminants. Changes to groundwater flow patterns could also have disruptive effects on the environment and other users. Surface disturbances would be caused by methods requiring construction. Noise, air pollution, traffic, etc., may occur during construction/operation. In some cases, effects associated with disposal of excavated materials may be significant.	The purpose of withdrawal is to reduce contaminant concentrations in the subsurface but there could be major potential side-effects associated with the surface disposal of withdrawn contaminants (or treated residuals). Additional impacts possible from pumping and gravity drainage are related to alteration of groundwater flow patterns (e.g., lowering of the water table and salt-water intrusion). Noise, air pollution, traffic, etc., may occur during construction/operation.	Possible side-effects are related to the transferral of contaminants to the atmosphere. Disposal of treatment byproducts (including solutions from regeneration) could also have adverse effects depending on disposal methods chosen.	Major side-effects are associated with the potential for reactions between reagents used in degradation methods and the hydrogeologic environment (e.g., resulting in contaminant residues). For water table adjustment, side-effects my result from both raising the water table (e.g., flooding of sewers, leach fields, or basements) and lowering the water table (e.g., base flow alterations and effects on wells). Natural processes are slow, and the risk exists that contamination will spread further.	Major potential environmental and social side-effects include disruption of normal use patterns, disruption of economic activity, public concern, continued presence of and potential spreading of contaminants, and health risks (e.g., if contaminants are not removed and/or treated). Possible environmental and social disruption accompany source removal.
Labor considerations	The construction/installation of material barriers tends to require skilled professionals; operational requirements are minimal (and would relate to performance monitoring). Other methods require minimal labor, and skill requirements are variable. Only hydrodynamic barriers in this category generally have labor requirements during operation that are in addition to non-labor intensive monitoring and supervision.	Methods are generally labor-intensive and require skilled professionals during construction/installation; operational requirements tend to be non-labor intensive but still require skilled professionals.	Methods are generally labor-intensive and require skilled professionals during construction/installation. Operational requirements are generally non-labor intensive, but skilled professionals are still required. One exception is biological detoxification which has labor-intensive operational requirements.	Degradation methods are generally non-labor intensive but specially trained technical personnel are required for construction/installation. Water table adjustment is labor intensive in its construction/installation but non-labor intensive in its operation; skilled personnel are required.	Labor requirements vary by method. Methods are generally non-labor intensive during construction/installation; skilled personnel are often not essential. Operational requirements are often minimal.

Condition	Containment	Withdrawal	Treatment	In-situ Rehabilitation	Management Options
Safety considerations for workers	Processes requiring the removal of contaminated material (e.g., construction activities) require special handling and safety precautions.	Drilling activities produce contaminated materials and require special handling precautions. The handling of contaminated excavated materials poses a serious limitation on the use of excavation. Labor requirements generally increase as the dangers posed by contaminants increase.	Exposure to contaminants can result from residuals handling, volatization, and other factors. For example, in air stripping, volatiles could be introduced into the atmosphere.	Safety considerations could be significant if the handling of materials that are potentially reactive is required.	Safety considerations vary among options. For example, they could be important for monitoring activities. Concern about workers is usually overshadowed by concern to protect the public more generally.
Time requirements	Unforeseen geotechnical conditions, complex hydrogeology, and extent of contamination are major factors in determining time for construction/installation. Time for design is generally less than two months (grouting and hydraulic barriers may require upwards of six months). Time for construction is generally two to six months for barrier methods and under two months for other methods. There are minimal time requirements during operation.	Hydrogeology and extent and nature of contamination are major factors. Time for design and construction/installation are each typically less than six months. Excavation may take as long as one year depending on areal extent and depth of excavation and existence of structures, e.g., utilities. Operation of pumping may take many years, depending on the extent of contamination, hydrogeology, and degree of cleanup to be achieved.	Time for design is typically less than six months. Time for construction/installation is typically less than six months. Design and vendor delivery are major time considerations. Time requirements for operating the system depend on contaminant types, concentration levels, and performance goals.	Degradation methods are possible either to design or construct/install within about one month if contaminants are familiar; otherwise, time requirements could be longer. Water table adjustment design and construction/installation are each on the order of six months, but maintenance of the system over the long-term is required.	Time requirements vary by option; they are generally less than six months each for design and construction/installation. Long lead times may be required in some cases, e.g., for developing alternative supplies and implementing health advisories. Termination/limitation of aquifer use and purchase of alternative supplies are often used for a rapid emergency response. Institutional considerations could constrain timely implementation of many methods.

Condition	Containment	Withdrawal	Treatment	In-situ Rehabilitation	Management Options
Cost considerations	Principal factors determining costs include depth to groundwater contamination, areal extent of contamination to be contained, geotechnical conditions, and type of contaminants. Containment methods are generally capital intensive during construction/installation; operational costs are generally minimal except for natural containment (e.g., analysis) and hydraulic barrier options. Replacement costs are likely to be incurred. The cost of maintaining surface seals used in conjunction with slurry walls is significant.	Principal factors determining costs include depth to groundwater contamination, volume of contaminated groundwater to be pumped, geotechnical conditions, availability of disposal and/or treatment facilities, and hydrogeology. Generally, these methods are capital intensive during construction/installation. System components may need to be selectively replaced depending on length of time of system operation; otherwise, operational costs are generally minimal.	Principal factors determining costs include flow rates and system capacity, concentration and types of contaminants, and plant design. Costs are highly variable among treatment options; the most costly methods include reverse osmosis, ion exchange, and electrodialysis. Home treatment units (at point-of-end use) are also costly.	Principal factors determining costs include: the size of sites and type and concentration of contaminants for degradation methods, and the extent of the system and duration of operation for water table adjustment.	Costs vary among options; they could include components related to enforcement, providing public information, and emergency responses.
Performance vis-a-vis the continued presence of contaminants	Containment results in the continued presence of contaminants in the subsurface with the potential for further migration (e.g., via leakage).	Withdrawal per se results in the continued presence of contaminants which are transferred to other environmental media; however, withdrawal methods are typically used in conjunction with treatment.	Treatment has the potential to result in the continued presence of contaminants through their possible transfer to other environmental media (e.g., air); additional contaminants may also be introduced (e.g., treatment byproducts). Removal efficiencies of methods are variable.	These methods result in the presence of transformed contaminants in the subsurface together with (spent) transformation agents.	These methods often result in the continued presence of contaminants in the subsurface with the potential for further migration.

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Condition	Containment	Withdrawal	Treatment	In-situ Rehabilitation	Management Options
Design life and operational requirements	Design life of material barrier containment systems is finite but as yet unknown. Long records of experience are generally lacking but design life tends to be 20-40 years for applications not involving contaminants. Replacement may be eventually required unless barriers are coupled with withdrawal/treatment. Hydrodynamic techniques must operate perpetually to isolate contaminants, requiring periodic well/pump replacement. Techniques for managing surface runoff can require more frequent maintenance than underground structures.	Only excavation is permanent. Design life of other methods will vary and a continuous maintenance/replacement schedule would be required. Fluid withdrawal methods could have long operation and maintenance periods (e.g., for highly attenuated contaminants).	Typically, design life is 15-30 years for equipment other than membranes (which is less than 5 years). Exceptions include filtration and ion exchange which have a design life of 15 years but which also require more frequent filter regeneration. Home units are prone to bacterial growth and require careful maintenance. Data are not available to evaluate ultrafiltration since this method has been operational only about 4-8 years. In general, replacement will be required at the end of design life if contaminants remain.	Design life is not typically a limitation. (Use of machinery or semi-permanent construction materials are not generally required.)	Design life is not always a limitation. Exceptions include purchasing of alternative supplies and point-of-end use treatment which both tend to be short-term (less than 5 years). In addition, the performance of point-of-end use treatment units has been known to shift dramatically over time. Developing alternative supplies may have a design life upwards of 50 years. The design life of municipal treatment facilities is generally on the order of 20-30 years.
Institutional considerations	Institutional considerations include the ease of land access and the presence of facilities and structures at the construction site.	Water rights issues may restrict the use of pumping. Other considerations include the availability of disposal alternatives for withdrawn contaminants and the ease of land access.	A major consideration involves the availability of alternatives for the disposal of treatment residues.	Regulatory approval may be required for the injection of degradation reagents.	A wide range of institutional considerations may arise depending on the option and includes enforcement, competing uses, access to alternative supplies (e.g., purchasing alternative supplies), and public acceptance.

[a] Based on Woodward-Clyde Consultants, Inc., 1983.

Source: Office of Technology Assessment.

F.3 APPLICATION OF CORRECTIVE ACTION ALTERNATIVES TO SOURCES

Source Category	Containment	Withdrawal	Treatment	In-situ Rehabilitation	Management Options
Category I (Designed to discharge)	Most containment methods[a] are generally applicable to all Category I sources except injection wells because of their depth. Only natural containment appears applicable to injection wells.	All withdrawal methods are applicable to almost all Category I sources. The exception is injection wells which are typically too deep for gravity drainage, gas venting, or excavation methods; in practice, mechanical integrity testing and annular pressure tests are used to detect problems from injection wells in lieu of corrective actions.	N.R.[b]	While all in-situ rehabilitation methods are generally applicable to most Category I sources, site-specific factors (e.g., geology, hydrology, and contaminants) must be evaluated to determine method feasibility. One exception may be injection wells which are typically too deep for degradation methods.	Most management options[c] are generally applicable to all Category I sources. In practice, corrective actions are generally limited to management options for sub-surface percolation.
Category II (Designed to store, treat, and/or dispose)	Most containment methods[a] are generally applicable to all Category II sources. Contaminant-specific evaluations are typically required to assure compatibility of radionuclides and any material barrier.	All withdrawal methods are generally applicable to all Category II sources. Withdrawal enhancement is not generally applicable to radioactive disposal sites.	N.R.[b]	Applicability of in-situ rehabilitation methods to most Category II sources depends on site-specific factors. In particular, tendency for methods to be contaminant-specific may limit use for multiple-contaminant situations. In addition, in-situ rehabilitation methods would generally be inapplicable to radioactive wastes; natural restoration would be inapplicable to sources containing some types of hazardous wastes; and degradation would be inapplicable to dredging conditions.	Most management options[c] are generally applicable to all Category II sources.

Source Category	Container	Withdrawal	Treatment	In-situ Rehabilitation	Management Options
Category III (Designed to transport or transmit)					
	Most containment methods[a] are generally applicable to all Category III sources.	All withdrawal methods are generally applicable to all Category III sources.	N.R.[b]	Degradation methods are generally applicable to Category III sources, especially if the contaminants involved are petroleum-based. In other cases, site-specific factors must be evaluated to determine feasibility of in-situ rehabilitation methods.	Most managment options[c] are generally applicable to all Category III sources.
Category IV (Discharge as a consequence of other activities)					
	Most containment methods[a] are technically applicable to all Category IV sources. However, experience to date is limited in terms of the areal extent and volumes handled; these factors could effectively preclude methods from addressing some Category IV sources.	All withdrawal methods are technically applicable to almost all Category IV sources. Exceptions include deicing salts application, which is not amenable to withdrawal enhancement methods, and mining and mine drainage which, if the mine is too deep, will not be amenable to gravity drainage or excavation. Volumes and areal extent could effectively preclude use of these methods, however, for practical reasons.	N.R.[b]	While in-situ rehabilitation methods are generally applicable to most Category IV sources, site-specific factors must be evaluated to determine feasibility. Degradation methods, however, are typically not used for deicing salts.	Most management options[c] are generally applicable to all Category IV sources. Due to the dispersed nature of contaminating activities, and to the high volumes and large areal extent of groundwater affected, corrective actions may be limited to management options in practice.

Source Category	Containment	Withdrawal	Treatment	In-situ Rehabilitation	Management Options
Category V (Provide conduit or induce discharge via altered flow patterns)					
	The applicability of most containment methods[a] to most Category V sources depends on well depth. For example, oil wells, geothermal wells, enhanced recovery wells, and solution mining are typically too deep for any of these methods. Only natural containment would not generally be restricted by depth; limited experience is available using hydraulic barriers for these deep sources. In general, application of any corrective action alternative to Category V sources depends on mechanical condition of wells. Most methods are applicable to construction excavation.	The applicability of some withdrawal methods (e.g., gravity drainage, excavation, and gas venting) to most Category V sources depends on well depth. For example, oil wells, geothermal wells, enhanced recovery wells, and solution mining are typically too deep for these methods. Withdrawal enhancement is not applicable to geothermal or water supply wells. Only pumping is generally unconstrained in its application to Category V sources. All methods are applicable to construction excavation.	N.R.[b]	The applicability of different in-situ rehabilitation methods varies by source. Site-specific factors must be evaluated to determine the feasibility of natural process restoration. With respect to degradation methods, oil wells and enhanced recovery wells are typically too deep, and geothermal wells have an unfavorable temperature (high) and chemical makeup (brine). Lowering of the water table may be inappropriate for water supply wells.	Most management options[c] are generally applicable to all Category V sources.
Category VI (Naturally-occurring)					
	Most methods[a] are generally applicable to all Category VI sources.	Most methods generally are applicable to all Category VI sources. Constraining factors include depth of the source and areal extent and volume of groundwater affected.	N.R.[b]	Water table adjustment is likely to be applicable to all Category VI sources. Natural process restoration is unlikely to be applicable. Degradation methods are typically not used for salts.	Most management options[c] are generally applicable to all Category VI sources.

[a] Neither sheet piles nor cement grout cutoffs have generally performed well in practice for these sources. Performance of all methods involving material barriers are dependent on compatibility with contaminants present and geologic conditions.

[b] The source, per se, of contamination is generally not relevant to the choice of treatment technologies except insofar as it indicates which specific contaminants may be present, contaminant concentrations, or the degree of contaminant removal desired.

[c] Source substitution or source removal may not be economically feasible or politically viable for some sources in this category.

Source: Office of Technology Assessment

Appendix G

Federal Efforts To Correct Groundwater Contamination

G.1 CORRECTIVE ACTION PROVISIONS FOR CATEGORY I SOURCES (p. 447)
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G.1 CORRECTIVE ACTION PROVISIONS FOR CATEGORY I SOURCES

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Subsurface Percolation	Safe Drinking Water Act - Underground Injection Control Program (40 CFR 144 and 146)	Cesspools or other waste receiving devices with open bottoms and sometimes perforated sides (Class V wells). Applies only to units serving 20 or more persons.	Not specified.	o No specific corrective action requirements. o If there may be a violation of primary drinking water regulations or if the presence of a contaminant may be adversely affecting the health of persons, enforcement or administrative actions can be taken to prevent the violation or adverse effect.
Injection Wells - Hazardous Waste	Safe Drinking Water Act - Underground Injection Control Program (40 CFR 144 and 146)[a]	Wells that inject hazardous waste (as defined by RCRA) beneath the deepest formation containing, within one-quarter mile of the well bore, an underground source of drinking water (Class I wells).	Not specified.	o Aquifer cleanup shall be prescribed by the regulatory authority if it is deemed necessary and feasible to ensure adequate protection of all underground sources of drinking water. o If there may be a violation of primary drinking water regulations or if the presence of a contaminant may be adversely affecting the health of persons, enforcement or administrative actions can be taken to prevent the violation or adverse effect.
		Wells that inject hazardous waste (as defined by RCRA) into or above a formation containing, within one-quarter mile of the well bore, an underground source of drinking water (Class IV wells).	Not specified.	o No specific corrective action requirements. o If there may be a violation of primary drinking water regulations or if the presence of a contaminant may be adversely affecting the health of persons, enforcement or administrative actions can be taken to prevent the violation or adverse effect.

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Injection Wells - Hazardous Waste (Continued)	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Wells that release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	Not specified.	Responses can be "removal" (short-term, emergency) actions or "remedial" (longer term, consistent with permanent remedy) actions. Remedial actions can be taken only at sites on the National Priorities List and must be consistent with requirements specified in National Contingency Plan. Selection of a remedy is based on a determination of cost-effectiveness (lowest cost alternative that is technologically feasible and reliable and which effectively mitigates and minimizes damage to and provides adequate protection of public health, welfare, or the environment).
Injection Wells - Non-Hazardous Waste	Safe Drinking Water Act - Underground Injection Control Program (40 CFR 144 and 146)	Wells that inject waste beneath the deepest formation containing, within one-quarter mile of the well bore, an underground source of drinking water (Class I wells).	Not specified.	Same as requirements for hazardous waste disposal wells that inject beneath the deepest source of drinking water under SDWA.
Injection Wells - Non-Waste	Safe Drinking Water Act - Underground Injection Control Program (40 CFR 144 and 146)	Wells used in connection with oil and gas production which inject fluids (Class II wells). Includes wells used for enhanced recovery, for storage of liquid hydrocarbons, and for wells where injected fluids are brought to the surface and may be combined with waste waters from gas plants.	Not specified.	Same as requirements for hazardous waste disposal wells that inject beneath the deepest sources of drinking water under SDWA.
		Wells used for extraction of minerals (Class III wells). Includes mining of sulfur by Frasch process, in-situ production of uranium and other metals, and solution mining of salts or potash.	Not specified.	Same as requirements for hazardous waste disposal wells that inject beneath the deepest source of drinking water under SDWA.

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Injection Wells - Non-Waste (Continued)	Safe Drinking Water Act - Underground Injection Control Program (40 CFR 144 and 146) (continued)	Wells not included in Categories I, II, III, and IV (Class V wells). Examples of Class V wells include artificial recharge wells, cooling water, or air conditioning return flow wells.	Not specified.	o No specific corrective action requirements. o If there may be a violation of primary drinking water regulations or if the presence of a contaminant may be adversely affecting the health of persons, enforcement or administrative actions can be taken to prevent the violation or adverse effect.
Land Application - Wastewater	Clean Water Act - Section 201 (40 CFR 35; 41 FR 6190, 2/11/76)	Wastewater land treatment processes (includes slow rate, rapid infiltration, and overland flow methods).	Not specified.	o No specific corrective action requirements. o However, if project is funded as Innovative and Alternative Technology, grant assistance may be awarded for the modification or replacement of projects that have not met design performance specifications (unless failure is due to negligence), correction of failure requires significantly increased capital or operating and maintenance expenditures, and failure occurs within the two-year period following final inspection.
Land Application - Wastewater Byproducts	Clean Water Act Section 405 (40 CFR 257)	Sewage sludge application (includes agricultural, forest and land reclamation utilization, and dedicated land disposal).	Not specified.	Same as requirements for land application of wastewater under CWA Section 201.
Land Application - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Land treatment of hazardous wastes (as defined by RCRA).	Corrective action program must prevent specified hazardous constituents from exceeding their respective limits established in the groundwater protection standard. (See app. E.1 on Monitoring Provisions for a description of the groundwater protection standard.)	o Corrective action program must be conducted at the compliance point and between the compliance point and the downgradient facility property boundary, as necessary to meet the cleanup standard. Corrective actions are not required beyond the downgradient facility property boundary. o Hazardous constituents must be removed or treated in place. Facility permit will specify the corrective action measures to be taken.

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Land Application - Hazardous Waste (Continued)	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)			o Corrective action must begin within a reasonable time period after groundwater protection standard is exceeded (time period specified in facility permit). o Corrective action measures must be continued during and beyond the compliance period to the extent necessary to ensure that the groundwater protection standard is not exceeded. Corrective action measures continued beyond the compliance period may be terminated if corrective action monitoring (see app. E.1) indicates that the groundwater protection standard has not been exceeded for three consecutive years. o The effectiveness of corrective action measures must be reported to the regulatory authority. If a corrective action program no longer satisfies the regulatory requirements, appropriate changes must be submitted within 90 days. o Enforcement action can also be taken under Section 7003 - Imminent and Substantial Endangerment
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Land application facilities that release any hazardous substance, pollutant, or contaminant (as defined by CERCLA).	Not specified.	Same as CERCLA provisions for hazardous waste disposal wells.
Land Application Non-Hazardous waste	Clean Water Act - Section 404 (40 CFR 230)	Disposal sites for dredged or fill material.	Not specified for groundwater.	No corrective action requirements specified for groundwater.

[a] RCRA and SWDA have overlapping jurisdiction for injection wells used to dispose of hazardous wastes. A permit-by-rule approach has been instituted to coordinate the requirements of both programs. An owner or operator of such a well must comply with all applicable SDWA technical requirements pursuant to the Underground Injection Control Program and certain RCRA administrative requirements. (See 40 CFR 144.14.)

Source: Office of Technology Assessment.

G.2 CORRECTIVE ACTION PROVISIONS FOR CATEGORY II SOURCES

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Landfills Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Landfills used for the disposal of hazardous waste (as defined by RCRA).	Corrective action program must prevent specified hazardous constituents from exceeding their respective limits established in the groundwater protection standard (see app. E.2 on monitoring provisions for a description of the groundwater protection standard).	o Corrective action program must be conducted at the compliance point and between the compliance point and the downgradient facility property boundary, as necessary to meet the cleanup standard. Corrective actions are not required beyond the downgradient facility property boundary. - Hazardous constituents must be removed or treated in place. Facility permit will specify the corrective action measures to be taken. - Corrective action measures must be continued during and beyond the compliance period to the extent necessary to ensure that the groundwater protection standard is not exceeded. Corrective action measures continued beyond the compliance period may be terminated if corrective action monitoring (see app. E.2) indicates that the groundwater protection standard has not been exceeded for 3 consecutive years. - The effectiveness of corrective action measures must be reported to the regulatory authority. If a corrective action program no longer satisfies the regulatory requirements, appropriate changes must be submitted within 90 days. o Enforcement action can be taken under Section 7003 - Imminent and Substantial Endangerment.
	Toxic Substances Control Act - Section 6 (40 CFR 761)	Chemical waste landfills used for the disposal of PCBs at concentrations of 50 ppm and above.	Not specified.	o Explicit corrective action requirements are not specified in the regulations. o PCB facilities determined to be in violation of the disposal regulations are subject to civil penalty and enforcement provisions of TSCA.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Landfills that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Not specified.	Responses can be "removal" (short-term, emergency) actions or "remedial" (longer term, consistent with permanent remedy) actions. Remedial actions can be taken only at sites on the National Priorities List and must be consistent with requirements specified in National Contingency Plan. Selection of a remedy is based on a determination of cost-effectiveness (lowest cost alternative that is technologically feasible and reliable and which effectively mitigates and minimizes damage to and provides adequate protection of public health, welfare, or the environment).

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Landfills — Sanitary	Resource Conservation and Recovery Act - Subtitle D (40 CFR 257)	Sanitary landfills defined as facilities which pose no reasonable probability of adverse effects on health or the environment from disposal of solid waste (as defined by RCRA).	Not specified.	No specific corrective action requirements.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Sanitary landfills that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
Open Dumps (including illegal dumping) - Waste	Resource Conservation and Recovery Act - Subtitle D (40 CFR 257)	Open dumps defined as facilities which do not meet the criteria for sanitary landfills under RCRA.	Not specified.	No specific corrective action requirements. Facilities must close or be upgraded to meet criteria for sanitary landfills under Subtitle D of RCRA.
	Comprehensive Environmental Response Compensation, and Liability Act (40 CFR 300)	Open dumps that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
Residential Disposal	Federal Insecticide, Fungicide, and Rodenticide Act - Section 19 (40 CFR 165)	Burial of small quantities of pesticide containers in open fields (containers which held organic or metallo-organic pesticides except organic mercury, lead, cadmium, or arsenic compounds).	No requirements established.	No requirements established.

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Surface Impoundments Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Surface impoundments used for the treatment, storage, or disposal of hazardous waste (as defined by RCRA).	Same as requirements for hazardous waste landfills under RCRA.	Same as requirements for hazardous waste landfills under RCRA.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Surface impoundments that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as requirements for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
Surface Impoundments Non-Hazardous Waste	Surface Mining Control and Reclamation Act (30 CFR 816 and 817)	Impoundments defined as all water, sediment, slurry or other liquid or semi-liquid holding structures and depressions, either naturally formed or artificially built. Structures may be temporary or permanent. Applies to all surface and underground coal mining operations.	Not specified.	All possible steps must be taken to minimize any adverse impact to the environment or public health and safety resulting from noncompliance with any permit condition including, but not limited to: (i) any accelerated or additional monitoring necessary to determine the nature and extent of noncompliance and the results of such actions; (ii) immediate implementation of measures necessary to comply with permit conditions (e.g. hydrologic reclamation plan, as described in app. H.4); and (iii) warning, as soon as possible after learning of such noncompliance, any person whose health and safety is in imminent danger due to the noncompliance.

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Surface Impoundments Non-Hazardous Waste (continued)	Federal Land Policy and Management Act[a]			
	- Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23). Covers minerals such as coal, phosphates, asphalt, sodium, potassium, sand, stone, gravel, and clay.	Impoundments used for the treatment or control of runoff and drainage during mining operations on Federal lands.	Not specified.	Mining plan submitted to the regulatory authority must include provisions for reclamation of disturbed areas. Regulations specify that adequate measures must be taken to correct damage to the environment and to public health and safety.
	- U.S. Mining Laws (43 CFR 3800) Cover locatable minerals such as gold, silver, lead, iron, and copper.	Not explicitly mentioned in the regulations. However, impoundments are part of mining operations. Applies only to operations on Federal lands.	Not specified.	Plan of operations submitted to the regulatory authority must include provisions for reclamation of disturbed areas.
	- Geothermal Steam Act (30 CFR 270 and BLM Operational Order No. 4)	Pits and sumps used to retain all materials and fluids necessary to drilling, production, or other operations on Federal lands.	Not specified.	Adverse environmental impacts from geothermal-related activity must be prevented or mitigated through enforcement of applicable standards and the application of existing technology.

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Waste Tailings	Federal Land Policy and Management Act - Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23)	Not explicitly mentioned in the regulations. For the purposes of this table, however, waste tailings are considered part of mining operations on Federal lands.	Not specified.	Same as requirements for non-hazardous waste surface impoundments under these laws.
	- U.S. Mining Laws (43 CFR 3800)	Not explicitly defined in the regulations, but disposal of waste tailings is mentioned as part of a mining operation.	Not specified.	Same as requirements for non-hazardous waste surface impoundments under these laws.
	Uranium Mill Tailings Radiation Control Act[b] - Active Sites (40 CFR 192)	Disposal areas covered by the regulations containing waste tailings from uranium processing activities. Such areas include the region within the perimeter of an impoundment or pile.	Same as standard for hazardous waste surface impoundments under RCRA.	Same as requirements for hazardous waste surface impoundments under RCRA.
	Uranium Mill Tailings Radiation Control Act - Inactive Sites (40 CFR 192)	Processing sites designated by DOE containing residual radioactive materials at which all or substantially all of the uranium was produced for sale to a Federal agency prior to Jan. 1, 1971.	Not specified.	o Decision on whether to institute remedial action, what specific action to take, and cleanup levels should be made on a site-specific basis. o Factors to consider include technical feasibility of improving the aquifer in its hydrogeologic setting, the cost of restorative or protective programs, the present and future value of the aquifer as a water resource, the availability of alternative water supplies, and the degree to which human exposure is likely to occur.

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Waste Piles Hazardous Waste	Resource Conservation and Recovery Act – Subtitle C (40 CFR 264)	Waste piles used for the treatment or storage of hazardous wastes (as defined by RCRA).	Same as standard for hazardous waste landfills under RCRA.	Same as requirements for hazardous waste landfills under RCRA.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Waste piles that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as standard for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
Waste Piles Non-Hazardous Waste	Surface Mining Control and Reclamation Act (30 CFR 816 and 817)	Refuse piles containing coal mine waste (includes coal processing waste and underground development waste). Applies to all surface and underground coal mining operations.	Same as standard for non-hazardous waste surface impoundments under SMCRA.	Same as requirements for non-hazardous waste surface impoundments under SMCRA.
	Federal Land Policy and Management Act			
	– Mineral leasing Act of 1920 and Materials Act of 1947 (43 CFR 23)	Not explicitly mentioned in the regulations. However, waste piles are part of mining operations. Applies only to Federal lands.	Same as standard for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.
	– U.S. Mining Laws (43 CFR 3800)	Not explicitly defined in the regulations, but waste piles are mentioned as part of a mining operation.	Same as standard for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Materials Stockpiles	Federal Insecticide, Fungicide, and Rodenticide Act (40 CFR 165)	Storage of packages and containers of pesticides.	No requirements established.	o No requirements established. o It is recommended that materials such as adsorptive clay, hydrated lime, and sodium hypochlorite be obtained for emergency treatment or detoxification of spills or leaks.
Graveyards	—	—	—	—
Animal Burial	—	—	—	—
Aboveground Storage Tanks - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Aboveground tanks used for the treatment or storage of hazardous wastes (as defined by RCRA).	Not specified.	o No requirements are established for groundwater contamination per se. o Contingency plan must specify procedures to be used to respond to tank spills or leakage, including procedures and timing for expeditious removal of leaked or spilled waste and repair of the tank.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Storage tanks that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as standard for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
	Toxic Substances Control Act (40 CFR 761)	See TSCA requirements, below, for hazardous waste containers.	—	—
Aboveground Storage Tanks - Non-Hazardous Waste	—	—	—	—

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Aboveground Storage Tanks - Non-Waste	Clean Water Act - Section 311 (40 CFR 112)	Onshore and offshore facilities with above-ground capacities of greater than 1,320 gallons of oil (or single tanks with capacities greater than 660 gallons).[c]	Not specified.	o No requirements are established for groundwater contamination per se. o The Spill Prevention Control and Countermeasure (SPCC) Plan should provide for prompt correction of visible leaks. In those instances where a facility has experienced spill events, the SPCC Plan must include a description of the spill, corrective actions taken, and plans for preventing a recurrence (if experience indicates a reasonable potential for equipment failure, the plan should also include a prediction of the direction, rate of flow, and total quantity of oil which could be discharged).
	Hazardous Liquid Pipeline Safety Act (49 CFR 195)	Storage of hazardous liquids (as defined by HLPSA) incidental to their movement by pipeline in or affecting interstate or foreign commerce. Regulations explicitly define aboveground "breakout tanks" which are used to relieve surges in a hazardous liquid pipeline system or to receive and store hazardous liquid transported by a pipeline. Requirements do not apply to Federal facilities.[d]	Not specified.	No requirements established.
Underground Storage Tanks - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Covered underground tanks used for the treatment or storage of hazardous waste as defined by RCRA.	Regulations for underground tanks have not been promulgated.	Regulations for underground tanks have not been promulgated.

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Underground Storage Tanks - Hazardous Waste (continued)	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Storage tanks that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as standard for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
Underground Storage Tanks - Non-Hazardous Waste	—	—	—	—
Underground Storage Tanks - Non-Waste	Clean Water Act - Section 311 (40 CFR 112)	Onshore facilities with underground storage capacities equal to or greater than 42,000 gallons.	Not specified.	No requirements are established for groundwater contamination per se.
Containers - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Containers used for the storage of hazardous wastes (as defined by RCRA).	Not specified.	o No requirements are established for groundwater contamination per se. o Spilled or leaked waste and accumulated precipitation must be removed from collection or containment system in as timely a manner as necessary to prevent overflow of the system.
	Toxic Substances Control Act - Section 6 (40 CFR 761)	Containers used to store PCBs at concentrations of 50 ppm and above. Container means any package, can, bottle, bag, barrel, drum, tank, or other device.	Not specified.	o No requirements are established for groundwater contamination per se. o Spilled or leaked material must be immediately cleaned up, using solvents or other adequate means.

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Containers Hazardous Waste (continued)	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Containers that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as standard for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
Containers Non-Hazardous Waste	—	—	—	—
Containers Non-Waste	Federal Insecticide, Fungicide, and Rodenticide Act (40 CFR 165)	Pesticide containers.	See standard for materials stockpiles under FIFRA.	See requirements for materials stockpiles under FIFRA.
Open Burning and Detonation Sites	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Open burning and detonation of waste explosives.[e]	Regulations have not been promulgated.	Regulations have not been promulgated.

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Open Burning and Detonation Sites (continued)	Federal Insecticide, Fungicide, and Rodenticide Act (40 CFR 165)	Open burning of small quantities of combustible pesticide containers which held organic or metallo-organic pesticides (except organic mercury, lead, cadmium, or arsenic compounds).	Same as standard for residential disposal (burial) under FIFRA.	Same as requirements for residential disposal (burial) under FIFRA.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Sites which release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as standard for hazardous waste landfills under CERCLA.	Same as requirements for hazardous waste landfills under CERCLA.
Radioactive Disposal Sites	Atomic Energy Act (10 CFR 60)[f]	Geologic repositories for high-level radioactive wastes.	No requirements established.	No requirements established.
	Atomic Energy Act (10 CFR 61)[g]	Disposal sites for low-level radioactive waste.	No requirements established.	The licensee must have plans for taking corrective measures if migration of radionuclides would indicate that specified performance objectives may not be met (see app. H.2, for performance objectives).
	Atomic Energy Act[h]	Sites identified by DOE that were used for the storage and processing of nuclear materials.	No requirements established.	No requirements established.

Source: Office of Technology Assessment.

[a] The Federal Land Policy and Management Act (FLPMA) of 1976 (P.L. 94-579) requires that public lands be managed in a manner that will protect the quality of environmental values. In addition, there are a number of laws regulating certain mining activities on Federal lands. The mining regulations are authorized by both the FLPMA and the specific mining laws and are thus presented together in this table. Note that regulations for the Geothermal Steam Act were redesignated, with minor revisions, as 43 CFR 3260 on Sept. 30, 1983.

[b] The requirements presented in this table are the Health and Environmental Protection Standards promulgated by EPA (40 CFR 192, 48 FR 45926, Oct. 7, 1983). NRC has also promulgated licensing requirements (10 CFR 30, 40 70 and 150).

[c] Facilities include those engaged in drilling, producing, gathering, storing, processing, refining, transferring, distributing, or consuming oil and oil products. Oil is defined as oil of any kind or in any form, including but not limited to petroleum, fuel oil, sludge, oil refuse, and oil mixed with wastes other than dredged spoil.

[d] Hazardous liquids include petroleum, petroleum products, and anhydrous ammonia. Although the regulations only mention "breakout tanks," tanks used for storage purposes are also covered by the statutes. Regulations for such storage tanks have not been established by DOT.

[e] Waste explosives include waste which has the potential to detonate and bulk military propellants which cannot safely be disposed of through other modes of treatment. Regulations for permitted facilities have not been promulgated. Interim status regulations for open burning and detonation do not establish corrective action requirements.

[f] The requirements presented are those established by NRC for high-level radioactive wastes; these requirements are proposed regulations. See 46 FR 35280, July 8, 1981. EPA has also published proposed health and environmental standards. See 47 FR 58196, Dec. 29, 1982.

[g] The requirements presented are those established by NRC for low-level radioactive waste sites. EPA is also required to establish health and environmental standards for such sites; standards have not yet been promulgated by EPA.

[h] The cleanup of these sites is not explicitly mandated by legislation. However, two programs have been instituted by DOE under the general authorization of the Atomic Energy Act. The Formerly Utilized Sites Remedial Action Program was established in 1974 for identifying and decommissioning former nuclear materials storage and processing facilities (and vicinity properties). The Surplus Facilities Management Program was established in 1978 for decommissioning DOE owned or operated radioactive contaminated facilities. Decommissioning standards have not yet been established by EPA.

Source: Office of Technology Assessment.

G.3 CORRECTIVE ACTION PROVISIONS FOR CATEGORY III SOURCES

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Pipelines — Hazardous Materials	Hazardous Liquid Pipeline Safety Act (49 CFR 195)	Pipelines used to transport hazardous liquids (includes petroleum, petroleum products, and anhydrous ammonia).	Not specified.	No requirements established.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Pipelines that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Not specified.	Responses can be "removal" (short-term, emergency) actions or "remedial" (longer term, consistent with permanent remedy) actions. Remedial actions can be taken only at sites on the National Priorities List and must be consistent with requirements specified in National Contingency Plan. Selection of a remedy is based on a determination of cost-effectiveness (lowest cost alternative that is technologically feasible and reliable and which effectively mitigates and minimizes damage to and provides adequate protection of public health, welfare, or the environment).
Pipelines — Non-Hazardous Materials	—	—	—	—
Materials Transport and Transfer Operations — Hazardous Materials and Waste	Hazardous Materials Transportation Act (49 CFR 171)	The transportation of hazardous materials and hazardous waste (as defined by HMTA) by rail car, aircraft, vessel, and motor vehicles used in interstate and foreign commerce (and motor vehicles used to transport hazardous waste in intrastate commerce).	No requirements established.	No requirements established.
	Comprehensive Environmental Response, Compensation, and Liability Act (40 CFR 300)	Transport-related accidents that release any hazardous substance, pollutant or contaminant (as defined by CERCLA).	Same as standard for pipelines under CERCLA.	Same as requirements for pipelines under CERCLA.

Source: Office of Technology Assessment.

G.4 CORRECTIVE ACTION PROVISIONS FOR CATEGORY IV SOURCES

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Irrigation Practices	Clean Water Act - Section 208 (40 CFR 35, Subpart G)[a]	Return flows from irrigated agriculture.	No requirements established.	No requirements established.
Pesticide Applications	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Agriculturally related non-point sources of pollution.	Same as standard for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.
	Federal Insecticide, Fungicide, and Rodenticide Act	Application of certain pesticides which may cause unreasonable adverse effects on the environment.	No requirements established.	No requirements established.
Fertilizer Applications	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Agriculturally related non-point sources of pollution.	Same as standard for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.
Animal Feeding Operations	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Runoff from manure disposal areas and from land area used for livestock.	Same as standard for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.
De-icing Salts Application	—	—	—	—

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Urban Runoff	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Urban stormwater runoff systems.	No requirements established.	No requirements established.
Percolation of Atmospheric Pollutants	—	—	—	—
Mining and Mine Drainage -				
Surface Mining	Clean Water Act - Section 208 (40 CFR, 35, Subpart G)	Mine-related sources of pollution including runoff from new, active, and abandoned surface and underground mines.	No requirements established.	No requirements established.
	Federal Land Policy and Management Act[b]			
	- Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23)	Mining of minerals such as coal, phosphate, asphalt, sodium, potassium, sand, stone, gravel and clay (on Federal lands).	Not specified.	Mining plan submitted to the regulatory authority must include provisions for reclamation of disturbed areas. Regulations specify that adequate measures must be taken to correct damage to the environment and to public health and safety. Groundwater is not explicitly addressed.
	- U.S. Mining Laws	Mining of minerals such as gold, silver, lead, iron and copper (on Federal lands).	Not specified.	Plan of operations submitted to the regulatory authority must include provisions for reclamation of disturbed areas. Groundwater is not explicitly addressed.
	Surface Mining Control and Reclamation Act (30 CFR 816)	Surface mining of coal.	Not specified.	All possible steps must be taken to minimize any adverse impact to the environment or public health and safety resulting from noncompliance with any permit condition including, but not limited to:

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Mining and Mine Drainage - Surface Mining (continued)	Surface Mining Control and Reclamation Act (30 CFR 816) (continued)			(i) any accelerated or additional monitoring necessary to determine the nature and extent of noncompliance and the results of such actions; (ii) immediate implementation of measures necessary to comply with permit conditions (e.g. hydrologic reclamation plan, as described in app. H.4); and (iii) warning, as soon as possible after learning of such noncompliance, any person whose health and safety is in imminent danger due to the noncompliance.
	Surface Mining Control and Reclamation Act (30 CFR 874 and 876)	Lands and water which were mined (covers coal mining and mining of minerals and materials other than coal) or which were affected by such mining, wastebanks, processing or other methods prior to Aug. 3, 1977.	Not specified.	o No requirements established. o Grants are available to the States for reclamation activities.
	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Mine-related sources of pollution including runoff from new, active, and abandoned surface and underground mines.	No requirements established.	No requirements established.
Underground Mining	Federal Land Policy and Management Act[a]			
	- Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23)	Mining for minerals such as coal, phosphate, asphalt, sodium, potassium, sand, stone, gravel and clay (on Federal lands).	Same as standard for surface mining under these laws.	Same as requirements for surface mining under these laws.
	- U.S. Mining Laws (43 CFR 3800)	Mining for minerals such as gold, silver, lead, iron and copper (on Federal lands).	Same as standard for surface mining under these laws	Same as requirements for surface mining under these laws.

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Mining and Mine Drainage - Underground Mining (continued)	Surface Mining Control and Reclamation Act (30 CFR 817)	Underground coal mining.[c]	Same as standard for surface mining under SMCRA.	Same as requirements for surface mining under SMCRA.

[a] 40 CFR 35, Subpart G are the regulations for State grants for Water Quality Planning, Management, and Implementation. Although the Clean Water Act is directed at the protection of surface waters, some States have chosen to include groundwater quality programs in their water quality management plans. Such plans are required by the regulations to indicate recognition that groundwater and surface water are interrelated.

[b] The Federal Land Policy and Management Act (FLPMA) of 1976 (P.L. 94-579) requires that public lands be managed in a manner that will protect the quality of environmental values. In addition, there are a number of laws regulating certain mining activities on Federal lands. The mining regulations are authorized by both the FLPMA and the specific mining laws and are presented together in this table.

[c] Applies to surface effects of underground mining.

Source: Office of Technology Assessment.

G.5 CORRECTIVE ACTION PROVISIONS FOR CATEGORY V SOURCES

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Production Wells-Geothermal and Heat Recovery	Federal Land Policy and Management Act[a] - Geothermal Steam Act (30 CFR 270 and BLM Operational Order No.4)	Wells used for the development of geothermal steam on Federal lands.	Not specified.	Adverse environmental impacts from geothermal-related activity must be prevented or mitigated through enforcement of applicable standards and the application of existing technology.
Production Wells - Water Supply	—	—	—	—
Other Wells (non-waste)- Monitoring Wells	—	—	—	—
Other wells (non-waste)- Exploration Wells	Federal Land Policy and Management Act - Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23)	Exploration wells used in mining operations for minerals such as coal, phosphate, asphalt, sodium, potassium, sand, stone, gravel, and clay (on Federal lands).	No requirements established.	No requirements established.
Construction Excavation	Clean Water Act - Section 208 (40 CFR 35, Subpart G)[b]	Construction activity related to sources of pollution.	No requirements established.	No requirements established.

[a] The Federal Land Policy and Management Act (FLPMA) of 1976 (P.L. 94-579) requires that public lands be managed in a manner that will protect the quality of environmental values. In addition, there are a number of laws regulating certain mining activities on Federal lands. The mining regulations are authorized by both the FLPMA and the specific mining laws and are thus presented together in this table. Note that regulations for the Geothermal Steam Act were redesignated, with minor revisions, as 43 CFR 3260 on Sept. 30, 1983.

[b] 40 CFR 35, Subpart G are the regulations for State grants for Water Quality Planning, Management, and Implementation. Although the Clean Water Act is directed at the protection of surface waters, some States have chosen to include groundwater quality programs in their water quality management plans. Such plans are required by the regulations to indicate recognition that groundwater and surface water intermix.

Source: Office of Technology Assessment.

G.6 CORRECTIVE ACTION PROVISIONS FOR CATEGORY VI SOURCES

Source	Statutory Authority	Definition of Source	Cleanup Standard	Corrective Action Provisions
Groundwater — Surface Water Interaction	Clean Water Act — Section 208 (40 CFR 35, Subpart G)[a]	Intermixing of groundwater and surface water.	No requirements established.	No requirements established.
Natural Leaching	Reclamation Act	Natural salt deposits affecting underground water supplies.	No requirements established.	o No requirements established. o Water development projects undertaken by the BLM have involved corrective actions due to saline conditions of groundwater.
Salt-water Intrusion	Clean Water Act — Sections 208 (40 CFR 35, Subpart G)[a]	Salt-water intrusion into rivers, lakes, and estuaries resulting from reduction of fresh-water flow from any cause, including groundwater extraction.	Same as standard for groundwater-surface interactions under CWA.	Same as requirements for groundwater-surface water interactions under CWA.
	Coastal Zone Management Act	Salt-water intrusion.	No requirements established.	No requirements established.

[a] 40 CFR 35, Subpart G are the regulations for State grants for Water Quality Planning, Management, and Implementation. Although the Clean Water Act is directed at the protection of surface waters, some States have chosen to include groundwater quality programs in their water quality management plans.

Source: Office of Technology Assessment.

Appendix H

Federal Efforts To Prevent Groundwater Contamination

H.1 DESIGN AND OPERATING PROVISIONS FOR CATEGORY I SOURCES (p. 471)
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H.1 DESIGN AND OPERATING PROVISIONS FOR CATEGORY I SOURCES

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Subsurface Percolation	Clean Water Act Section 201 (40 CFR 35, Subpart E)	Individual systems defined as privately owned alternative wastewater treatment works serving one or more principal residences or small commercial establishments which are neither connected into nor part of any conventional treatment works (e.g., on-site systems with localized treatment and disposal of wastewater).	Achieve established water quality goals of the act.	o No specific design requirements. o States are required to consider the cost-effective use of individual systems as part of overall systems or part of overall planning efforts for construction of municipal waste treatment systems.	Not applicable.	Not applicable.
	Safe Drinking Water Act - Underground Injection Control Program (40 CFR 144 and 146)	Cesspools or other waste receiving devices with open bottoms and sometimes perforated sides (included in Class V well category). Applies only to units serving 20 or more persons.	Demonstrate that activity will not be conducted in a manner that allows movement of contaminants into underground sources of drinking water so that there may not be compliance with National Interim Drinking Water Regulations or so that the health of persons may not be otherwise adversely effected.	o Regulations specifying design and operating requirements for Class V wells have not been promulgated. o Owners and operators are only required to submit inventory information (e.g., location, type and operating status of the well).	Regulations have not been promulgated for Class V wells.	No requirements established under the UIC Program.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Injection Wells-Hazardous Waste	Safe Drinking Water Act - Underground Injection Control Program[a] (40 CFR 144 and 146)	Wells that inject hazardous waste (as defined by RCRA) beneath the deepest formation containing, within one-quarter mile of the well bore, an underground source of drinking water (Class I wells)	Demonstrate that activity will not be conducted in a manner that allows movement of contaminants into underground sources of drinking water.	o Location must be identified of all known wells within the injection zone, and measures must be undertaken for wells which are improperly sealed, completed, or abandoned to prevent any movement of fluid into underground sources of drinking water. o Well location and construction requirements (well casing, cementing, and use of packers to prevent contaminant migration) must be complied with. o Appropriate tests and logs must be conducted during drilling and construction. o Information on fluid pressure, temperature, fracture pressure and other data on the physical and chemical characteristics of injection matrix and formation fluids must be collected. o During operation, injection pressure must not exceed a maximum calculated level to assure that new fractures are not initiated, that existing fractures are not propagated, and that injection fluids do not move into underground sources of drinking water. Injection between outermost well casing and underground source of drinking water is prohibited. Pressure must be maintained on annulus between well tubing and casing and it must be filled with fluid. (Any failures associated with a well during operation must be corrected.)	Certification by an independent registered professional engineer must be submitted to regulatory authority (pursuant to RCRA).	No requirements established under the UIC Program.
		Wells that inject hazardous wastes (as defined by RCRA) into or above a formation containing, within one-quarter mile of the well bore, an underground sources of drinking water (Class IV wells)	Regulations have not been promulgated for Class IV wells.	Regulations prohibit permitting of new Class IV wells which inject hazardous waste into an underground source of drinking water and require such existing wells to be prohibited over a period of 6 months following approval of a State UIC Program. Regulations specifying design and operating requirements for Class IV wells have not been promulgated.	Regulations have not been promulgated for Class IV wells.	Regulations have not been promulgated for Class IV wells.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Injection Wells - Non-Hazardous Waste	Safe Drinking Water Act - Underground Injection Control Program (40 CFR 144 and 146)	Wells that inject waste beneath the deepest formation containing, within one-quarter mile of the well bore, an underground source of drinking water (Class I wells)	Same as objective for hazardous waste injection wells that inject beneath the deepest underground sources of drinking water.	Same as requirements for hazardous waste wells that inject beneath the deepest underground sources of drinking water.	Wells must be plugged with cement in accordance with specified methods (unless an alternative method is approved by regulatory authority) so that movements of fluids into or between underground sources of drinking water are not allowed.	Same as requirements for hazardous waste injection wells that inject beneath the deepest underground sources of drinking water.
		Wells used in connection with oil and gas production which inject fluids (Class II wells). Includes wells used for enhanced recovery, for storage of liquid hydrocarbons and for wells where injected fluids are brought to the surface and may combine with waste waters from gas plants.	Same as objective for hazardous waste injection wells that inject beneath the deepest underground sources of drinking water.	o Compliance is required with siting and construction (casing and cementing requirements). Exemption from casing and cementing requirements for existing wells is allowed if earlier regulations and any State regulations were met and injected fluid will not migrate into underground sources of drinking water and create a significant risk to the health of persons. o Appropriate tests and logs must be conducted during drilling and construction. o Infomation on fluid pressure, estimated fracture pressure, and physical and chemical characteristics of the injection zone must be collected. o Operating requirements are the same as for hazardous waste wells that inject beneath the deepest underground sources of drinking water.	Same as requirements for Class I wells (non-hazardous waste).	Same as requirements for hazardous waste injection wells that inject beneath the deepest underground sources of drinking water.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Injection Wells - Non-Hazardous Waste (Continued)	Safe Drinking Water Act - Underground Injection Control Program (40 CFR 144 and 146) (Continued)	Wells used for extraction of minerals (Class III wells). Includes mining of sulfur by Frasch process, in-situ production of uranium and other metals, and solution mining of salts or potash.	Same as objective for hazardous waste injection wells that inject beneath the deepest underground sources of drinking water.	o Compliance is required with construction (casing and cementing) requirements. Exemption from requirements is allowed where there is substantial evidence that no contamination or underground source of drinking water would result. o Appropriate tests and logs must be considered during drilling and construction. o Information on fluid pressure, estimated fracture pressure, and physical and chemical characteristics of the injection zone must be collected. o Operating requirements are the same as for hazardous waste wells that inject beneath the deepest underground sources of drinking water.	Same as requirements for Class I wells (non-hazardous waste).	Same as requirements for hazardous waste injection wells that inject beneath the deepest underground sources of drinking water.
		Wells not included in Categories I, II, III, and IV (i.e., Class V wells). Examples of Class V wells include artificial recharge wells, and cooling water or air conditioning return flow wells.	Demonstrate that activity will not be conducted in a manner that allows movement of contaminants into underground sources of drinking water so that there may not be compliance with National Interim Drinking Water Regulations or so that the health of persons may not be otherwise adversely affected.	o Regulations specifying design and operating requirements for Class V wells have not been promulgated. o Owners and operators are only required to submit inventory information (e.g., location, type, and operating status of the well).	Regulations have not been promulgated for Class V wells.	No requirements established under the UIC Program.
Land Application - Wastewater	Clean Water Act - Section 201 (40 CFR 35)	Wastewater land treatment processes (includes slow rate, rapid infiltration and overland flow methods). May be funded under Innovative and Alternative Technologies Program.	If groundwater is a potential supply of drinking water, the National Interim Drinking Water Regulations must not be exceeded. If background levels are higher than the NIDWRs, there should not be an increase in that level. (Continued next page)	o Criteria for best practicable waste treatment technology must be met. Design and operating requirements are not specified. o Technical guidance manual contains information on site planning (includes selection of site), investigations (pre-design), process design, and operation and maintenance.	No requirements established.	No requirements established (see discussion on corrective actions, app. G.1).

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Land Application - Wastewater (Continued)	Clean Water Act - Section 201 (40 CFR 35) (Continued)		If groundwater is used as drinking water supply, conditions above should be met (levels for biological contaminants should not be exceeded where water is used without disinfection). If groundwater is used for purposes other than drinking water, criteria established on a case-by-case basis based on present or potential use of the groundwater.			
Land Application - Wastewater Byproducts	Clean Water Act - Section 201 and 405 (40 CFR 257)	Sewage sludge application (includes agricultural, forest and land reclamation utilization and dedicated land disposal). May be funded under Innovative and Alternative Technologies Program.	For underground drinking water sources, background levels or National Interim Primary Drinking Water Regulations (if higher than background level) must not be exceeded beyond the application boundary or an alternative boundary established on a site-specific basis.	o In addition to the performance standard for groundwater, performance criteria are also established for floodplains, surface water, application to land used for flood-chain crops, disease, air and safety. Design and operating requirements not specified. o Technical guidance manual contains information on site planning, field investigations, process design and operation and maintenance.	No requirements established.	No requirements established (see discussion on corrective action, app. G.1).

Source	Statutory Authority	Definition of Source	Performance Standard	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Land Application - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Land treatment of hazardous waste (as defined by RCRA). Requirements do not apply to land treatment facilities (or portions of facilities) that received waste prior to the effective date of the RCRA regulations (Jan. 28, 1983).	Hazardous constituents entering the groundwater must not exceed background levels, the Maximum Contaminant Levels for 14 constituents specified by the National Interim Drinking Water Regulations (if higher than background) or alternative concentration limits (established on a site-specific basis) beyond a specified compliance point.	o Site requirements limited to floodplain and seismic considerations. o Prior to application of hazardous waste, it must be demonstrated (by fixed tests, laboratory analyses, available data) that hazardous waste constituents can be completely degraded, transformed or immobilized in the treatment zone. o Design and operating conditions will be specified in permit based on demonstration conditions. o Runoff must be minimized; run-on controls and runoff management systems must be installed. o Wind dispersal of particulates must be controlled. Growth of food-chain crops may be allowed if it can be demonstrated that it will not cause substantial risk to human health.	o Design and operating conditions must be met through closure period. o Vegetative cover must be established on portion of facility being closed (so that cover will not substantially impede degradation, transformation, or immobilization of hazardous constituents in treatment zone). Cover should not require extensive maintenance. o Exemption from cover requirement is allowed if treatment zone soil does not exceed background values by a statistically significant amount. o Monitoring (see app. E.1) is to be continued through closure period (unsaturated zone monitoring may be terminated after 90 days).	o Post closure care period is 30 years (unless period is reduced or extended by regulatory authority). o All design, operating, monitoring (See app. E.1), and cover requirements must be met through post-closure period. o Exemption from post-closure requirements is allowed if treatment zone soil does not exceed background values by a statistically significant amount.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Land Application - Non-Hazardous Waste	Clean Water Act - Section 404 (40 CFR 230)	Disposal sites for dredged or fill material	Restore and maintain the chemical, physical, and biological integrity of waters of the United States.	o No specific design requirements. o Guidelines include actions that can be undertaken to minimize the adverse effects of discharge or dredged or fill material. One such action (specified in the regulations) is selecting discharge methods and disposal sites where the potential for erosion, slumping or leaching of material into the surrounding aquatic ecosystem will be reduced. Another action is to select the disposal site, the discharge point, and the method of discharge to minimize the extent of any plume.	No requirements established under the 404 program.	No requirements established under the 404 program.

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[a] RCRA and SWDA have overlapping jurisdiction for injection wells used to dispose of hazardous wastes. A permit-by-rule approach has been instituted to coordinate the requirements of both programs. An owner or operator of such a well must comply with all applicable SDWA technical requirements pursuant to the Underground Injection Control Program and certain RCRA administrative requirements.

Source: Office of Technology Assessment.

H.2 DESIGN AND OPERATING PROVISIONS FOR CATEGORY II SOURCES

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Landfills - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Landfills used for the disposal of hazardous wastes (as defined by RCRA). Requirements do not apply to facilities (or portions of facilities) that received waste prior to the effective date of the RCRA regulations (Jan. 26, 1983).	Hazardous constituents entering the groundwater must not exceed background levels, the Maximum Contaminant Levels for 14 constituents specified by the National Interim Drinking Water Regulations (if higher than background), or alternative concentration limits (established on a site-specific basis) beyond a specified compliance point.	o Siting requirements are limited to floodplain and seismic conditions. o All landfills must have a liner and leachate collection and removal system. Design and operating specifications are established in the facility permit. o Run-on controls and runoff management systems must be installed. o Wind dispersal of particulates must be controlled. o Special requirements apply to ignitable, reactive, or incompatible wastes and to containers in overpacked drums. Bulk liquids may only be disposed in landfills with liners and leachate collection systems. o Exemption from liner and leachate collection system requirements may be granted if the location and alternative design and operating provisions prevent migration of hazardous constituents. o Exemption from all groundwater monitoring requirements (see app. E.2) may be granted if regulatory authority finds there is no potential for migration of liquid from the facility to the uppermost aquifer through the post-closure period. o Exemption from detection monitoring program (see app. E.2) may be granted for facilities with double liners and leak detection systems between the liners. Liners must be repaired or replaced if a failure is detected.	Establish cover that minimizes liquid migration, requires minimal maintenance, promotes drainage, resists erosion or abrasion, accommodates settling and subsidence. Permeability should be less than or equal to liner or subsoils.	o Post-closure care period is 30 years (unless period is reduced or extended by regulatory authority). o All design and operating, monitoring, and cover requirements must be met through post-closure period. o Leachate collection system must be operated until leachate is no longer detected.
	Toxic Substances Control Act - Section 6 (40 CFR 761)	Chemical waste landfills used for the disposal of PCBs at concentrations of 50 ppm and above.	Not specified.	o Disposal facility shall be located in areas of low to moderate relief. Flood plains, shorelands, and groundwater recharge areas must be avoided, and there shall not be a hydraulic connection between the facility and surface water. o Diversion dikes are required to divert surface water runoff. (Continued next page)	No requirements established.	Surface water analysis reports (see monitoring requirements, app. E.2) and operating records must be retained for at least 20 years.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Landfills - Hazardous Waste (Continued)	Toxic Substances Control Act - Section 6 (40 CFR 761) (Continued)			o Bottom of landfill liner or soils must be 50 feet from historical high water table. o Landfill must be underlain by soils or synthetic membrane liner with permeability equal to or less than 10^{-7} cm/sec. o Leachate collection system must be installed. o Site must be operated and maintained in a manner to prevent safety problems or hazardous conditions resulting from spilled liquids and windblown material. o Bulk liquids exceeding 500 ppm may be disposed of provided such waste is pretreated and/or stabilized. o A waiver from any requirement may be approved by the regulatory authority if it can be demonstrated that operation of the landfill will meet the performance standard.		
Landfills - Sanitary	Resource Conservation and Recovery Act - Subtitle D (40 CFR 257)	Sanitary landfills defined as facilities which pose no reasonable probability of adverse effects on health or the environment from disposal of solid waste (as defined by RCRA).	For underground drinking water sources, background levels or National Interim Primary Drinking Water Regulations (if higher than background) must not be exceeded beyond the application boundary or an alternative boundary established on a site-specific basis.	o Design and operating requirements are not specified. o In addition to groundwater performance criteria, performance criteria are established for floodplains, surface water, application to land used for food-chain crops, disease, air, and safety.	No requirements established.	No requirements established.
Open Dumps (including illegal dumping) - Waste	Resource Conservation and Recovery Act - Subtitle D (40 CFR 257)	Open dumps defined as facilities which do not meet the criteria for sanitary landfills under RCRA.	Same as objective for sanitary landfills under Subtitle D of RCRA.	Open dumps must be closed or upgraded to meet the criteria established for sanitary landfills under Subtitle D of RCRA.	No requirements established.	No requirements established.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Residential Disposal	Federal Insecticide, Fungicide, and Rodenticide Act - Section 19 (40 CFR 165)	Burial of small quantities of pesticide containers in open fields (containers which held organic or metallo-organic pesticides except organic organic mercury, lead, cadmium, or arsenic compounds).[a]	Show due regard for protection of surface and subsurface water.	o Requirements are not specified. o Containers should be rinsed prior to disposal. (Rinse water and pesticide residues should be added to spray mixtures in the field or incinerated, disposed of in specially designated landfills, or chemically deactivated. Other disposal methods such as soil injection or chemical degradation should be undertaken with EPA guidance). o State and Federal pollution control standards should not be violated.	No requirements established.	No requirements established.
Surface Impoundments - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Surface impoundments used for the treatment, storage, or disposal of hazardous waste (as defined by RCRA). Requirements do not apply to facilities (or portions of facilities) that received waste prior to the effective date of the RCRA regulations (Jan. 26, 1983).	Same as objective for hazardous waste landfills under RCRA.	o Siting requirements are limited to floodplains and seismic conditions. o All surface impoundments must have a liner. Design and operating specifications are established in the facility permit. o All surface impoundments must be designed and operated to prevent overtopping and must have dikes to prevent massive failure. o Special contingency plans to address leaks or spills must be prepared (including provisions for immediate shut-down and emptying of the impoundment). o Special requirements apply to ignitable, reactive or incompatible waste. o Exemptions from certain design and monitoring requirements are the same as those for hazardous waste landfills.	o For storage or treatment impoundments: wastes and residue must be removed and sent to a permitted facility, and equipment must be decontaminated. o For disposal impoundments: eliminate free liquids and/or solidify wastes and residues, and stabilize remaining waste to support cover. o Cover requirements are the same as those for hazardous waste landfills.	Same as requirements for hazardous waste landfills.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Surface Impoundments - Non-Hazardous Waste	Surface Mining Control and Reclamation Act (30 CFR 816 and 817)	Impoundments defined as all water, sediment, slurry, or other liquid or semi-liquid holding structures and depressions, either naturally formed or artifically built. Structures may be temporary or permanent. Applies to all surface and underground coal mining operations.	Groundwater quality shall be protected by handling earth materials and runoff in a manner that minimizes acidic, toxic, or other harmful infiltration to groundwater systems and by managing excavations and other disturbances to prevent or control the discharge of pollutants into the groundwater.	o All impoundments must meet requirements for stability, prevention of overtopping and provision of spillways, and protection against surface erosion. Installation of a liner is not a mandatory requirement but may be required by the regulatory authority on a site-specific basis to meet the performance standard. o Permanent impoundments must not result in the diminution of the quality of water utilized by adjacent or surrounding landowners for agricultural, industrial, recreational or domestic use. The quality of water in the impoundment must be suitable on a permanent basis for its intended use, and after reclamation, must meet all applicable State and Federal standards.	o Temporary impoundments must be removed and reclaimed. o Permanent impoundments must meet all design and operating requirements, be maintained properly, meet the requirements of the reclamation plan and the requirements of the groundwater monitoring plan.	o A hydrologic reclamation plan must be submitted with a permit application which specifies the measures to be taken during the mining and reclamation operations to protect groundwater (on-site and off-site) from adverse effects (e.g., acid or toxic drainages). o A performance bond must be filed covering the duration of mining and reclamation activities. o Monitoring must be continued until bond release.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Surface Impoundments - Non-Hazardous Waste (Continued)	Federal Land Policy and Management Act[b]					
	- Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23). Covers minerals such as coal, phosphate, asphalt, sodium, potassium, sand, stone, gravel and clay.	Impoundments used for the treatment or control of runoff and drainage during mining operations on Federal lands.	Take adequate measures to avoid, minimize, or correct damage to the environment and to public health and safety while encouraging development of mineral resources.	o A mining plan must be submitted to the regulatory authority which includes a description of measures to be taken to prevent or control groundwater pollution. o Operations may be prohibited or restricted in areas if it is determined by the regulatory authority that water quality will be lowered below State standards or levels set by the Department of Interior (unless it is found that the lowering of water quality is necessary to economic and social development and will not preclude any assigned user of the water; EPA must be consulted to ensure that the Clean Water Act would not be violated).	o No specific requirements. o Mining plan must include provisions for reclamation of disturbed areas.	o No specific requirements. o Performance bond must be filed in an amount sufficient to satisfy the reclamation requirements of an approved mining plan (at least $2000).
	- U.S. Mining Laws (43 CFR 3800). Cover locatable minerals such as gold, silver, lead, iron and copper.	Not explicitly mentioned in the regulations. However, impoundments are considered part of mining operations. Applies only to Federal lands.	Prevent unnecesary or undue degradation of Federal lands which may result from mining operations.	o A plan of operations must be submitted to the regulatory authority which includes a description of measures to be taken to meet the performance standard.	o No specific requirements. o Plan of operations must include provisions for reclamation of disturbed areas.	o No specific requirements. o Performance bond must be filed in an amount based on the estimated cost of reasonable stabilization and reclamation of disturbed areas.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Surface Impoundments - Non-Hazardous Waste (Continued)	Federal Land Policy and Management Act (continued)					
	- Geothermal Stream Act (30 CFR 270 and BLM Operational Order No.4)	Pits and sumps used to retain all materials and fluids as necessary to drilling production or other operations on Federal lands.	Groundwaters must not be contaminated (specifies compliance with all Federal and State water quality standards).	Sources must be lined with impervious material.	o Impoundments must be filled, covered, and returned to a near natural state. o Impoundments must be purged of environmentally harmful chemicals and precipitates before backfilling.	o No requirements established.
Waste Tailings	Federal Land Policy and Management Act					
	- Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23)	Not explicitly mentioned in the regulations. However, they are part of mining operations. Applies only to Federal lands.	Same as objective for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.
	- U.S. Mining Laws (43 CFR 3800)	Not explicitly defined in the regulations, but disposal of waste tailings is mentioned as part of a mining operation.	Same as objective for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Waste Tailings (Continued)	Uranium Mill Tailings Radiation Control Act[c] - Active Sites (40 CFR 192)	Disposal areas covered by the regulations containing waste tailings from uranium processing activities. Such areas include the region within the perimeter of an impoundment or pile.	Same as objective for hazardous waste surface impoundments under RCRA except that compliance with the standard is required at all points at a greater distance than 500 meters from the edge of the disposal area and/or outside the site boundary.[d]	Same as requirements for hazardous waste surface impoundments under RCRA except that the exemption from groundwater monitoring requirements for double-lined facilities with leak detection systems does not apply.	o With respect to non-radiological hazards, site must be closed in a manner that: - minimizes the need for further maintenance; and - controls, minimizes, or eliminates, to the extent necessary to prevent threats to human health and the environment, post-closure escape of hazardous waste, hazardous waste constituents, leachate, contaminated rainfall, or waste decomposition products to the ground or surface waters or to the atmosphere. o With respect to radiological hazards, site must be designed to be effective for 1000	o See closure requirments. o No specific requirements established by EPA. NRC may require long term surveillance of the site as part of the license requirement.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Waste Tailings (Continued)	Uranium Mill Tailings Radiation Control Act[c] - Active Sites 40 CFR 192) (Continued)				years, to the extent reasonably achievable, and, in any case, for at least 200 years (limits for atmospheric releases are also specified).	
Waste Piles - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Waste piles used for the treatment or storage of hazardous wastes (as defined by RCRA). Requirements do not apply to facilities (or portions of facilities) that received waste prior to the effective date of the RCRA regulations (Jan. 26, 1983).	Same as objective for hazardous waste landfills under RCRA.	o Siting requirements are limited to floodplain and seismic conditions. o All waste piles must have a liner and leachate collection and removal system. Design and operating specifications are established in the facility permit. o Run-on controls and runoff management systems must be installed. o Wind dispersal of particulates must be controlled. o Special requirements apply to ignitable, reactive or incompatible wastes. o Exemption from liner and leachate collection system requirements may be granted if: - the waste pile is located inside or under a structure that provides protection from precipitation to prevent runoff generation of leachate; and - the location and alternative design and operating provisions prevent migration of hazardous constituents. o Exemption from all groundwater monitoring requirements (see app. E.2) may be granted if the regulatory authority finds there is no potential for migration of liquid from the facility to the uppermost aquifer through the post-closure period.	Wastes, waste residues, contaminated structures and equipment, and contaminated subsoils must be removed and sent to permitted facility.	If all contaminated subsoils are not removed, the post-closure requirements for hazardous waste landfills apply.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Waste Piles - Hazardous Waste (Continued)	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264) (Continued)			o Exemption from detection monitoring program (see app. E.2) may be granted for: - facilities with double liners and leak detection systems between the liners (liners must be repaired or replaced if a failure is detected); - facilities located inside or under a structure that provides protection from precipitation to prevent runoff generation of leachate; and - facilities with single liners and leachate collection systems located above the seasonal high water table (a liner inspection system must also be implemented).		
Waste Piles - Non-Hazardous Waste	Surface Mining Control and Reclamation Act (30 CFR 816 and 817)	Refuse piles containing coal mine waste (includes coal processing waste and underground development waste).[e] Applies to all surface and underground coal mining operations except those on Federal lands (leased coal).	Groundwater quality shall be protected by handling earth materials and runoff in a manner that minimizes acidic, toxic, or other harmful infiltration to groundwater systems and by managing excavations and other disturbances to prevent or control the discharge of pollutants into the groundwater.	o All waste must be placed in disposal areas certified by a registered professional engineer and approved by the regulatory authority.[f] Waste must be controlled to: minimize adverse effects of leachate and surface water runoff on surface and groundwater; ensure mass stability and prevent mass movement; ensure that the final disposal facility is suitable for reclamation; not create a public hazard; and prevent combustion. o If disposal area contains springs, natural or manmade water courses, or wet weather seeps, design must include diversions and underdrains as necessary to control erosion, prevent water infiltration, and ensure stability.	o Disposal area must be graded and covered. o No permanent impoundments are allowed on the completed refuse pile.	Same as requirements for non-hazardous waste surface impoundments under SMCRA.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Waste Piles - Non-Hazardous Waste	Federal Land Policy and Management Act - Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23)	Not explicitly mentioned in the regulations. However, they are considered part of mining operations. Applies only to Federal lands.	Same as objective for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.
	- U.S. Mining Laws (43 CFR 3800)	Not explicitly defined in the regulations, but waste piles are mentioned as part of a mining operation.	Same as objective for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.	Same as requirements for non-hazardous waste surface impoundments under these laws.
Materials Stockpiles	Federal Insecticide, Fungicide, and Rodenticide Act (40 CFR 165)	Storage of packages and containers of pesticides.	Provide for the safe storage of pesticides.	o No mandatory requirements are established. o Storage sites should be located: - where flooding is unlikely and where soil texture/structure and hydrogeologic characteristics will prevent contamination of any water system by runoff or percolation; and - with due regard to the amount, toxicity, and environmental hazard of pesticides, and the number and sizes of containers. o Drainage from the site should be contained (e.g. runoff or washwater from the decontamination of personnel and equipment) and if contaminated, disposed of in accordance with regulations (see Residential Disposal under FIFRA above). o Pesticides should be labeled and segregated by formulation as appropriate. o State and Federal pollution control standards should not be violated.	No requirements established.	No requirements established.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Graveyards	—	—	—	—	—	—
Animal Burial	—	—	—	—	—	—
Aboveground Storage Tanks - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Aboveground tanks used for the treatment or storage of hazardous wastes (as defined by RCRA).	Prevent spills or leakage.	o Tank shell must have sufficient strength to prevent rupture or collapse. Design specifications are established in the facility permit for the tank shell and for the foundation, structural support, seams and pressure controls of tank. o Tank or liner must be compatible with wastes. o Controls to prevent overfilling must be used. o Special requirements are established for ignitable, reactive, and incompatible wastes.	Wastes and waste residues must be removed and sent to a permitted facility.	No requirements established.
	Toxic Substances Control Act (40 CFR 761)	See TSCA requirements, below, for hazardous waste containers.				
Aboveground Storage Tanks - Non-Hazardous Waste	—	—	—	—	—	—
Aboveground Storage Tanks - Non-Waste	Clean Water Act - Section 311 (40 CFR 112)	Onshore facilities with above ground capacities equal to or greater than 1,320 gallons of oil (or single tanks with capacities greater than 660 gallons).[g]	Prevent discharged oil from reaching a navigable water course.[h]	o No specific requirements are established. o A Spill Prevention Control and Countermeasure (SPCC) Plan must be submitted to the regulatory arthority. The plan must discuss provisions for the compatibility of the tank with stored material, containment of spills, installation of engineering devices that provide warnings of tank failures, and other safeguards. Leakage due to defective internal heating coils should be controlled. Portable or mobile tanks should be located to prevent discharge into navigable waters.	No requirements established.	No requirements established.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Aboveground Storage Tanks - Non-Waste (Continued)	Hazardous Liquid Pipeline Safety Act (49 CFR 195)	Storage of hazardous liquids (as defined by HLPSA) incidental to their movement by pipeline in or affecting interstate or foreign commerce. Regulations explicitly define aboveground "breakout tanks" which are used to relieve surges in a hazardous liquid pipeline system or to receive and store hazardous liquid transported by a pipeline. Requirements do not apply to Federal facilities.[1]	Contain hazardous liquids in the event of a spill or leak.	Tank area must be adequately protected against unauthorized entry and relief venting must be provided for each tank.	No requirements established.	No requirements established.
Underground Storage Tanks - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Covered underground tanks used for the treatment or storage of hazardous waste as defined by RCRA.	Regulations have not been promulgated.	Regulations have not been promulgated.	Regulations have not been promulgated.	Regulations have not been promulgated.
Underground Storage Tanks - Non-Hazardous Waste	—	—	—	—	—	—

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Underground Storage Tanks - Non-Waste	Clean Water Act - Section 311 (40 CFR 112)	Onshore facilities with underground storage capacities equal to or greater than 42,000 gallons.	Prevent discharged oil from reaching a navigable water course.	o No specific requirements are established. o A Spill Prevention Control and Countermeasure (SPCC) Plan must be submitted to the regulatory authority. The plan must discuss provisions for the compatibility of the tank with stored material, protection from corrosion by coatings, cathodic protection or other effective methods compatible with local soil conditions, and the installation of engineering devices that provide warnings of tank failures, and other safeguards. Leakage due to defective internal heating coils should be controlled.	No requirements established.	No requirements established.
Containers - Hazardous Waste	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Containers used for the storage of hazardous wastes (as defined by RCRA).	Prevent spills or leakage.	o Container or liner must be compatible with wastes. o Storage area for containers must have an impervious base, controls and collection system for the control and removal of liquids, spills, and run-on (unless containers are elevated or protected from contact with liquid). Spill containment system is not required if containers do not contain liquids. o Special requirements are established for ignitable, reactive, and incompatible wastes.	o Wastes and waste residues must be removed and sent to a permitted facility. o Containers, liners, bases and soil contaminated with waste must be decontaminated or removed.	No requirements established.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Containers - Hazardous Waste (Continued)	Toxic Substances Control Act - Section 6 (40 CFR 761)	Containers used to store PCBs at concentrations of 50 ppm and above.	Not specified.	o Storage facilities for containers may not be located below the 100-year flood water elevation. o Storage facilities must provide adequate roofing, walls, floors and curbing to prevent rainwater from reaching containers and to contain any spills or leaks. o Temporary storage in areas that do not meet these requirements may be allowed for certain containers. o Containers must meet specified DOT regulations for shipping containers. o Containers above a specified size must meet SPCC requirements under Section 311 of the Clean Water Act and specified OSHA standards.	No requirements established.	No requirements established.
Containers - Non-Hazardous Waste	—	—	—	—	—	—
Containers - Non-Waste	Federal Insecticide, Fungicide and Rodenticide Act (40 CFR 165)	Pesticide containers	See objective for Materials Stockpiles under FIFRA	See requirements for Materials Stockpiles under FIFRA.	See requirements for Materials Stockpiles under FIFRA.	See requirements for Materials Stockpiles under FIFRA.
Open Burning and Detonation Sites	Resource Conservation and Recovery Act - Subtitle C (40 CFR 264)	Open burning and detonation of waste explosives[j]	Regulations have not been promulgated.	Regulations have not been promulgated.	Regulations have not been promulgated.	Regulations have not been promulgated.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Open Burning and Detonation Sites (Continued)	Federal Insecticide, Fungicide, and Rodenticide Act (40 CFR 165)	Open burning of small quantities of combustible pesticide containers which hold organic or metallo-organic pesticides (except organic mercury, lead, cadmium, or arsenic compounds).	Same as standard for residential disposal (burial) under FIFRA.	Same as requirements for residential disposal (burial) under FIFRA.	Same as requirements for residential disposal (burial) under FIFRA.	Same as requirements for residential disposal (burial) under FIFRA.
Radioactive Disposal Sites	Atomic Energy Act (40 CFR 191)	Geologic repositories for high-level radioactive wastes.[k]	Disposal systems must be designed to provide a reasonable expectation that for 10,000 years after disposal, reasonably foreseeable releases of waste into the accessible environment are projected to be less than specified amounts (very unlikely releases are projected to be less than ten times specified amounts).	o Disposal systems must not be located where there has been mining for resources or where there is a reasonable expectation of exploration in the future. o Disposal systems must be selected and designed to keep releases as small as reasonably achievable (taking technical, social and economic considerations into account) and so that removal of most wastes is not precluded for a reasonable period of time after disposal. o Disposal systems must use several types of barriers (engineered and natural) to isolate wastes.	Sites must be identified by markers and records.	Disposal systems must not rely on active institutional controls (e.g. controlling or containing releases, maintenance operations, or remedial actions) to isolate wastes beyond a reasonable time period (e.g. a few hundred years) after disposal.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Radioactive Disposal Sites (Continued)	Atomic Energy Act (10 CFR 61)[1]	Low-level radioactive waste disposal sites.	Radioactive material released into groundwater must not exceed levels specified in the regulations.	o Requirements specified are for near-surface disposal. o Site design features must be directed toward long-term isolation and avoidance of the need for continuing active maintenance after closure. o Site design and operation must be compatible with closure and stabilization plan and lead to closure that provides reasonable assurance that performance objectives will be met. o Site must be designed to complement and improve the ability of the site's natural characteristics to assure that perfomance objectives will be met. o Site must be designed to minimize to the extent practicable the contact of water with waste during and after disposal. o Requirements related to the placement of wastes in the disposal site are specified. o A buffer zone of land must be maintained between any buried waste and the disposal site boundary and beneath the disposed waste.	o Covers must be designed to minimize to the extent practicable water infiltration, to direct percolating or surface water away from the waste and to resist degradation by surface geologic processes and biotic activity. o Boundaries and locations of each disposal unit must be accurately located and mapped by means of a land survey.	o Active institutional controls may not be relied upon for more than 100 years. o Post-closure surveillance period will be determined by NRC on a case-by-case basis.

Source: Office of Technology Assessment.

[a] A farmer disposing of pesticides from his own use, which are hazardous wastes, is exempt from RCRA requirements, provided each emptied pesticide container is triple rinsed in accordance with EPA regulations and pesticide residues are disposed of on his own farm in a manner consistent with the disposal instructions on the pesticide label (40 CFR 262.51).

[b] The Federal Land Policy and Management Act (FLPMA) of 1976 (P.L. 94-579) requires that public lands be managed in a manner that will protect the quality of environmental values. In addition, there are a number of laws regulating certain mining activities on Federal lands. The mining regulations are authorized by both the FLPMA and the specific mining laws and are thus presented together in this table. Note that regulations for the Geothermal Steam Act were redesignated, with minor revisions, as 43 CFR 3260 on Sept. 30, 1983.

[c] The requirements presented in this table are the Health and Environmental Protection Standards promulgated by EPA. The NRC also has promulgated licensing requirements for uranium mill tailings (see 10 CFR 30, 40, 70, and 150).

[d] Concentration limits for combined radium-226 and radium-228 (5 pC/liter) and gross alpha-particle activity (15 pC/liter excluding radon and uranium) are added to the standard.

[e] Coal processing waste means earth materials which are separated and wasted from the product coal during cleaning, concentrating, or other processing or preparation of coal. Underground development waste means waste-rock mixtures of coal, shale, claystone, siltstone, sandstone, limestone, or related materials that are excavated, moved, and disposed of from underground workings in connection with underground mining activities (30 CFR 701.5).

[f] Coal mine waste may be disposed of in underground mine workings if approved by the regulatoty authority and the Mine Safety and Health Administration.

[g] Facilities include those engaged in drilling, producing, gathering, storing, processing, refining, transferring, distributing, or consuming oil and oil products. Oil is defined as oil of any kind or in any form, including but not limited to petroleum, fuel oil, sludge, oil refuse, and oil mixed with wastes other than dredged spoil.

[h] The provisions of Section 311 of the Clean Water Act are directed towards surface water. However, the design and operating requirements serve to protect against the discharge of oil that may also impact groundwater.

[i] Hazardous liquids include petroleum, petroleum products, and anhydrous ammonia.

[j] Waste explosives include waste which has the potential to detonate and bulk military propellants which cannot safely be disposed of through other modes of treatment. Regulations for permitted facilities have not been promulgated. Interim status regulations for open burning and detonation establish minimum distance requirements for such activities from the property of others (see 40 CFR 265).

[k] The requirements presented in this table are the health and environmental protection standards proposed by EPA (see 47 FR 58196, Dec. 29, 1982). NRC has also published proposed regulations for geologic repositories. (See 46 FR 35280, July 8, 1981.)

[l] The requirements in this table are the NRC licensing requirements. EPA has not promulgated health and environmental protection standards.

H.3 DESIGN AND OPERATING PROVISIONS FOR CATEGORY III SOURCES

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Pipelines - Hazardous Materials	Hazardous Liquid Pipeline Safety Act (49 CFR 195)	Pipelines used to transport hazardous liquids (includes petroleum, petroleum products and anhydrous ammonia).	To prevent leakage of hazardous liquids.	o Pipelines must be chemically compatible with the hazardous liquids. o Design requirements cover considerations of temperature, pressure (internal and external to pipeline), valves and other appurtenances connected to a pipe, and pumping units (and fabricated assemblies). o New pipelines must be constructed of steel. o Pipelines must be protected against corrosion. o Safety devices and spill or leak containment systems are required.	No requirements established.	No requirements established.
Pipelines - Non-Hazardous Waste	—	—	—	—	—	—
Materials Transport and Transfer Operations - Hazardous Materials and Waste	Hazardous Materials Transportation Act (49 CFR 171)	The transportation of hazardous materials and hazardous waste (as defined by HMTA) by rail car, aircraft, vessel and motor vehicles used in interstate and foreign commerce (and motor vehicles used to transport hazardous waste in intrastate commerce).	To protect against the risks to life and property which are inherent in the transportation of hazardous materials in commerce.	Regulations specify requirements regarding the preparation of materials for transport (e.g., packaging and container specifications); handling and loading; and labeling.	No requirements established.	No requirements established.

Source: Office of Technology Assessment.

H.4 DESIGN AND OPERATING PROVISIONS FOR CATEGORY IV SOURCES

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Irrigation Practices	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Return flows from irrigated agriculture.	Achieve established water quality goals of the act.	o No specific requirements are established. o States are required to submit water quality management plans which must describe the regulatory and non-regulatory activities and Best Management Practices (BMPs) selected to meet non-point source control needs. o BMPs are methods, measures, or practices to prevent or reduce water pollution (they include but are not limited to structural and nonstructural controls, and operation and maintenance procedures). BMPs can be applied before, during, and after pollution-producing activities to reduce or eliminate the introduction of pollutants into receiving waters. Economic, institutional, and technical factors must be considered.	No requirements established.	No requirements established.
Pesticide Applications	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Agriculturally related non-point sources of pollution.	Same as standard for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.
	Federal Insecticide, Fungicide, and Rodenticide Act - Section 3 (40 CFR 162)	Application of certain pesticides which may cause unreasonable adverse effects on the environment.	Prevent unreasonable adverse effects on the environment.	o No specific requirements. o A pesticide can be classified for "restricted use." (Restricted use classifications require that pesticides be applied by certified applicators. Restricted use is not explicitly defined to include geographic restrictions.)	No requirements established.	No requirements established.
Fertilizer Applications	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Agriculturally related non-point sources of pollution.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Animal Feeding Operations	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Runoff from manure disposal areas and from land used for livestock.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.
De-icing Salts Applications	—	—	—	—	—	—
Urban Runoff	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Urban stormwater runoff systems	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.
Percolation of Atmospheric Pollutants	—	—	—	—	—	—
Mining and Mine Drainage - Surface Mining	Clean Water Act - Section 208 (40 CFR 35, Subpart G)	Mine-related sources of pollution including runoff from new, active, and abandoned surface and underground mines.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.	Same as requirements for irrigation practices under CWA.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Mining and Mine Drainage - Surface Mining (Continued)	Federal Land Policy and Management Act[b]					
	- Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23)	Mining of minerals such as coal, phosphate, asphalt, sodium, potassium, sand, stone, gravel and clay (on Federal lands).	Take adequate measures to avoid, minimize, or correct damage to the environment and to public health and safety while encouraging development of mineral resources.	o Mining plan must be submitted to the regulatory authority which includes descriptions of measures to be taken to prevent or control groundwater pollution. o Operations may be prohibited or restricted in areas if it is determined by the regulatory authority that water quality will be lowered below State standards or levels set by DOI (unless it is found that the lowering of water quality is necessary to economic and social development and will not preclude any assigned uses of the water. EPA must be consulted to ensure that the Clean Water Act would not be violated.)	o No specific requirements. o Mining plan must include provisions for reclamation of disturbed areas.	o No specific requirements. o Performance bond must be filed in an amount sufficient to satisfy the reclamation requirements of an approved mining plan (at least $2000).
	- U.S. Mining Laws (43 CFR 3800)	Mining of minerals such as gold, silver, lead, iron and copper (on Federal lands).	Prevent unnecessary or undue degradation of Federal lands which may result from mining operations.	o Plan of operations must be submitted to the regulatory authority which includes a description of measures to be taken to meet the performance standard.	o No specific requirements. o Plan of operations must include provisions for reclamation of disturbed areas.	o No specific requirements. o Performance bond must be filed in an amount based on the estimated cost of reasonable stabilization and reclamation of disturbed areas.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Mining and Mine Drainage - Surface Mining (Continued)	Surface Mining Control and Reclamation Act (30 CFR 816)	Surface mining of coal.	Groundwater quality shall be protected by handling earth materials and runoff in a manner that minimizes acidic, toxic, or other harmful infiltration to groundwater systems and by managing excavations and other disturbances to prevent or control the discharge of pollutants into the groundwater.	o Regulatory authority is required to assess the cumulative hydrologic impacts of the mining operation prior to permit approval. o Permit application must contain a determination of the probable hydrologic consequences on the quality and quantity of ground and surface water under seasonal flow conditions for the proposed permit and adjacent areas. o Hydrologic reclamation plan must be submitted with the permit application. It must contain steps to be taken during mining and reclamation through bond release period to: minimize disturbances to the hydrologic balance within the permit and adjacent areas; prevent material damage outside the permit area; meet Federal and State water quality regulations; and protect the rights of present users. Specific measures to avoid acid or toxic drainage and to provide water treatment facilities, as necessary must be included in the plan.	Compliance with the hydrologic reclamation plan.	o A hydrologic reclamation plan must be submitted with a permit application which specifies the measures to be taken during mining and reclamation operations to protect groundwater (on-site and off-site) from adverse effects (e.g. acid or toxic drainage). A performance bond must be filed covering the duration of mining and reclamation activities. o Monitoring must be continued until bond release.
Mining and Mine Drainage - Underground Mining	Federal Land Policy and Management Act - Mineral Leasing Act of 1920 and Materials Act of 1947 (43 CFR 23)	Mining of minerals such as coal, phosphate, asphalt, sodium, potassium, sand, stone, gravel and clay (on Federal lands).	Same as standard for surface mining under these laws.	Same as requirements for surface mining under these laws.	Same as requirements for surface mining under these laws.	Same as requirements for surface mining under these laws.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Mining and Mine Drainage - Underground Mining (Continued)	- U.S. Mining Laws (43 CFR 3800)	Mining of minerals such as gold, silver, lead, iron and copper (on Federal lands).	Same as requirements for surface mining under these laws.	Same as requirements for surface mining under these laws.	Same as requirements for surface mining under these laws.	Same as requirements for surface mining under these laws.
	Surface Mining Control and Reclamation Act (30 CFR 816)	Underground coal mining[c]	Same as standard for surface mining under SMCRA.	Same as requirements for surface mining under SMCRA.	Same as requirements for surface mining under SMCRA.	Same as requirements for surface mining under SMCRA.

[a] 40 CFR 35, Subpart G are the regulations for State grants for Water Quality Planning, Management, and Implementation. Although the Clean Water Act is directed at the protection of surface waters, some States have chosen to include groundwater quality programs in their water quality management plans. Such plans are required by the regulations to indicate recognition that groundwaters and surface water intermix.

[b] The Federal Land Policy and Management Act (FLPMA) Act of 1976 (P.L. 94-579) requires that public lands be managed in a manner that will protect the quality of environmental values. In addition, there are a number of laws regulating certain mining activities on Federal lands. The mining regulations are authorized by both the FLPMA and the specific mining laws and are thus presented together in this table.

[c] Applies to surface effects of underground mining.

Source: Office of Technology Assessment.

H.5 DESIGN AND OPERATING PROVISIONS FOR CATEGORY V SOURCES

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Production Wells - Geothermal and Heat Recovery	Federal Land Policy and Management Act - Geothermal Steam Act (30 CFR 270 and BLM Operational Order No.4)[a]	Wells used for the development of geothermal steam (on Federal lands)	Must not contaminate groundwaters (compliance with all Federal and State water quality standards)	o All necessary precautions must be taken to keep wells under control, utilize trained and competent personnel, utilize properly maintained equipment and materials, and use operating practices which insure the safety and life and property. o A plan of operation must be approved (prior to commencing operations) by the regulatory authority which describes the proposed measures to be taken for the protection of the environment, including the prevention or control of pollution of surface and groundwater.	Wells must be plugged and abandoned in a manner approved by the regulatory authority.	No requirements established.
Production Wells - Water Supply	—	—	—	—	—	—
Other Wells (non-waste) - Monitoring Wells	—	—	—	—	—	—
Other wells (non-waste) - Exploration Wells	Federal Land Policy and Management Act[a] - Mineral Leasing Act of 1920 and Materials Act of 1949 (43 CFR 23)	Exploration wells used in mining operations for minerals such as coal, phosphate, asphalt, sodium, potassium, sand, stone, gravel, and clay (on Federal lands).	Take adequate measures to avoid, minimize, or correct damage to the environment and to public health and safety while encouraging development of mineral resources.	o Exploration plan must be filed with the regulatory authority including a description of measures to be taken to prevent or control pollution of surface and groundwater.	No requirements established.	No requirements established.

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Construction Excavation	Clean Water Act - Section 208 (40 CFR 35) Subpart G)[b]	Construction activity related to sources of pollution.	Achieve established water quality goals of the act.	o No specific requirements established. o States are required to submit water quality management plans which must describe the regulatory and non-regulatory activities and Best Management Practices (BMPs) selected to meet non-point source control needs. (BMPs are methods, measures, or practices to prevent or reduce water pollution. They include but are not limited to structural and nonstructural controls, and operation and maintenance procedures). BMPs can be applied before, during, and after pollution-producing activities to reduce or eliminate the introduction of pollutants into receiving waters. Economic, institutional, and technical factors must be considered.	No requirements established.	No requirements established.

[a] The Federal Land Policy and Management Act (FLPMA) of 1976 (P.L. 94-579) requires that public lands be managed in a manner that will protect the quality of environmental values. In addition, there are a number of laws regulating certain mining activities on Federal lands. The mining regulations are authorized by both the FLPMA and the specific minimum laws and thus presented together in this table. Note that regulations for the Geothermal Steam Act were redesignated, with minor revisions, as 43 CFR 3260 on Sept. 30, 1983.

[b] 40 CFR 35, Subpart G are the regulations for State Grants for Water Quality Planning, Management, and Implementation. Although the Clean Water Act is directed at the protection of surface waters, some States have chosen to include groundwater quality programs in their water quality management plans. Such plans are required by the regulations to indicate recognition that groundwaters and surface water intermix.

Source: Office of Technology Assessment.

H.6 DESIGN AND OPERATING PROVISIONS FOR CATEGORY VI SOURCES

Source	Statutory Authority	Definition of Source	Performance Objective/Criteria	Design and Operating Requirements	Closure Requirements	Post-Closure Care Requirements
Groundwater — Surface Water Interactions	Clean Water Act — Section 208 (40 CFR 35, Subpart G)[a]	Intermixing of groundwater and surface water.	Achieve established water quality goals of the act.	o No specific requirements established. o States are required to submit water quality management plans which must indicate recognition that groundwaters and surface water intermix.	No requirements established.	No requirements established.
Natural Leaching	Reclamation Act	Natural salt deposits affecting underground water supplies.	No objective specified.	o No specific requirements established. o Reclamation Act authorizes the Federal Government to develop water supplies for domestic, municipal, industrial, and other purposes.	No requirements established.	No requirements established.
Salt-water Intrusion	Clean Water Act — Section 208 (40 CFR 35, Subpart G)[a]	Salt-water intrusion into rivers, lakes, and estuaries resulting from reduction of freshwater flow from any cause, including groundwater extraction.	Achieve established water quality goals of the act.	o No specific requirements established. o States are required to submit water quality management plans which must describe the regulatory and non-regulatory activities and Best Management Practices (BMPs) selected to meet non-point source control needs. (BMPs are methods, measures, or practices to prevent or reduce water pollution. They include but are not limited to structural and nonstructural controls, and operation and maintenance procedures). BMPs can be applied before, during, and after pollution-producing activities to reduce or eliminate the introduction of pollutants into receiving waters. Economic, institutional, and technical factors must be considered.	No requirements established.	No requirements established.
	Coastal Zone Management Act	Salt-water intrusion.	Minimize the loss of property caused by salt-water intrusion.	o No specific requirements. o States may include provisions in their Coastal Zone Management Plans to address salt-water intrusion as appropriate.	No requirements established.	No requirements established.

[a] 40 CFR 35, Subpart G are the regulations for State grants for Water Quality Planning, Management, and Implementation. Although the Clean Water Act is directed at the protection of surface water, some States have chosen to include groundwater quality programs in their water quality management plans.

Source: Office of Technology Assessment.

Office of Technology Assessment

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